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Evaluation of Point Source Dispersion Models

by

Michael T. Mills, Roger Caiazza,
David D. Hergert, and David A. Lynn

Teknekron Research, Inc.
69 Hickory Drive
Waltham, Massachusetts 02154

Contract No. 68-02-3192

EPA Lead Project Officer: Russell F. Lee
Office of Air Quality Planning and Standards

EPA Co-Project Officer: John S. Irwin
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

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16. ABSTRACT

The purpose of this study is the evaluation of two Gaussian point source dispersion models by use of hourly meteorological, air quality and emissions data collected at 4 power plant monitoring networks. Two versions of the EPA CRSTER model, CRSTER (Turner) and CRSTER (Irwin), were evaluated. CRSTER (Turner) is the current EPA CRSTER Model, which used the so called Pasquill-Gifford-Turner (P-G-T) dispersion curves. CRSTER (Irwin) is a modification of the model based upon Irwin's horizontal and vertical dispersion curves. These models differ only in the choice of horizontal and vertical plume dispersion coefficients (σ_y and σ_z) and wind profile coefficients. The data for this model evaluation consists of hourly emissions, meteorological and SO_2 concentration data collected during the period 1974-1977 at the following networks operated by American Electric Power (AEP): Clifty Creek, Tanners Creek, Muskingum and Gavin-Kyger-Sporn. Three general approaches were used in this analysis: statistical summaries (Chapter V), a comparison of the characteristics of the observed and calculated 3-hour and 24-hour episodes (Chapter VI), and an analysis of selected individual episodes (Chapter VII).

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I. INTRODUCTION

The purpose of this study is the evaluation of two gaussian point source dispersion models by use of hourly meteorological, air quality and emissions data collected at 4 power plant monitoring networks. Two versions of the EPA CRSTER model, CRSTER (Turner) and CRSTER (Irwin), were evaluated. CRSTER (Turner) is the current EPA CRSTER Model[1], which uses the so- called Pasquill-Gifford-Turner (P-G-T)[2] dispersion curves. CRSTER (Irwin) is a modification of the model based upon Irwin's horizontal and vertical dispersion curves.[3] These models differ only in the choice of horizontal and vertical plume dispersion coefficients (σ_y and σ_z) and wind profile coefficients. Each of these models is discussed in more detail in Section IV. The data for this model evaluation consists of hourly emissions, meteorological and SO_2 concentration data collected during the period 1974-1977 at the following networks operated by American Electric Power (AEP): Clifty Creek, Tanners Creek, Muskingum and Gavin-Kyger-Sporn. Hourly SO_2 emissions estimates by stack for each coal fired power plant are derived from reported average monthly fuel sulfur content for the plant and hourly megawatt generation values for each individual unit. For this analysis, the wind and temperature data collected on site are supplemented with values of stability class and mixing height calculated from measurements taken at the most representative surface and upper air weather stations. A complete description of this model evaluation data base is given in Section III.

Obviously there is a limit to the extent which monitoring data can be used for the evaluation of dispersion models. These data can indicate whether there are basic problems with the model assumptions and in many cases can identify those individual factors responsible for unsatisfactory model performance. Higher resolution data from special field programs is generally required for actual model development and validation, unless one is willing to settle for a rather simple statistical model. Monitoring data does have an advantage over data from special field studies in that it is generally collected over a much longer time period and therefore reflects the influence of a wider range of meteorological conditions, a factor of considerable importance since NAAQS and PSD increments for SO_2 are expressed in terms of values which may be exceeded only once per year. The advantages and drawbacks to the use of monitoring network data for model evaluation are examined further in Section II.

Even with on-site wind direction data, the comparison of hourly measured and calculated concentrations on a station by station basis is of limited value for point source emissions due to the uncertainty of the plume centerline location. In place of this direct comparison, a statistical approach is required which involves the comparison of the cumulative frequency distributions of measured and calculated concentrations. This statistical evaluation of point source model performance is given in Section V. Also, the suitability of a particular point source model may be assessed through an analysis of the characteristics of those periods during which a selected number (e.g. 25) of high short term concentrations (measured and calculated) occur. For a point source model to be judged physically reasonable, it should not only successfully predict the downwind distance to the maximum concentration but should also identify the meteorological condition under which it occurs. The characteristics of observed and calculated short-term concentration episodes are described in Section VI followed in Section VII by a special analysis of selected episodes to determine whether either of the two models can possibly describe the spatial and diurnal variation of concentrations on these days. On the basis of these comparisons, conclusions and recommendations are made in Section VIII.

II. BACKGROUND

A. Model Evaluation Overview

The passage of the 1977 Clean Air Act Amendments has created the need for more accurate dispersion models for determination of compliance with Prevention of Significant Deterioration (PSD) increments for proposed new sources. Modeling is also required to specify the nature of emission offsets for those sources planning to locate in or near non-attainment areas. Dispersion model calculations will continue to serve as the basis for plans for the attainment and maintenance of ambient air quality standards.

For the evaluation of air quality impacts due to point source emissions in a rural area, EPA recommends the use of the CRSTER (Turner) Model[1] except for areas with very rough terrain. The basis of this model is the source oriented gaussian plume model with P-G-T[2] vertical and horizontal dispersion coefficients and the Briggs [4] plume rise calculation. One-hour concentrations are calculated for an array of receptor locations by use of an entire year's surface meteorological data which has been preprocessed to calculate hourly stability class as a function of wind speed, cloud cover and solar elevation angle according to the method suggested by Turner.[5] Hourly mixing heights are determined from morning and afternoon mixing heights through a stability dependent interpolation scheme. [1] The effect of terrain is simulated by reducing the plume height by an amount equal to the height of the receptor above the stack base. The hourly calculated concentrations are sorted to obtain the magnitude and location of the highest and second highest concentrations for 3-hour and 24-hour averaging times.

The use of CRSTER (Turner) for the evaluation of air quality impacts due to power plant emissions has been criticized on several grounds. The P-G-T dispersion curves used in the model are based upon experiments involving tracers released near ground level and do not necessarily describe the distribution of pollutants within tall stack plumes. A related concern is the A-stability condition which seems to give high short-term concentrations relatively close to the power plant stack. In particular, the American Meteorological Society (AMS) Workshop[6] on stability classification and sigma curves has expressed concern over the application of these curves for elevated releases. A more recent version of the model currently under development, CRSTER (Irwin), incorporates many of the AMS recommendations. In addition to the question of plume dispersion parameters, some experts feel that the "full height" terrain correction used in the model is overly conservative.

The Source Receptor Analysis Branch (SRAB) of EPA-OAQPS has sponsored a number of studies to evaluate the CRSTER (Turner) Model. The first of these studies [7] was performed using measured hourly SO_2 concentrations and on-site meteorological data for the oil fired Canal Power Plant in coastal Massachusetts. For each of the 4 receptors, the measured highest and second highest 1-hour SO_2 concentrations (corrected for background) were greater than the corresponding calculated values. This underprediction problem was not changed even when alternate combinations of National Weather Service (NWS) and on-site meteorological data were used as input to the model. Little correlation was found between measured and calculated 1-hour concentrations when a comparison was made on an hour by hour and site by site basis. This result was due in part to the fact that even on-site wind direction measurements do not give a true indication of the plume centerline location. Although the correlation improved when nearby model receptors at the same distance from the source were included in the analysis, there still appeared to be a problem with the model calculation of the magnitude and downwind distance of concentration peaks. This result may have been due to the coastal location of the plant. The underprediction of 24-hour average concentrations was even greater than for the 1-hour values. This problem with the 24-hour concentrations was traced partially to an underestimate of the horizontal dispersion coefficient for the 1-hour averaging time.

A similar CRSTER (Turner) model evaluation study [8] was performed for 3 coal fired power plants in Ohio: Stuart, Muskingum and Philo. For the first two plants the agreement between measured and calculated highest and second highest 1-hour SO_2 concentrations was better than in the Canal Plant study. The 1-hour concentrations for those receptors at 2.4 km from the Stuart plant and 4.3 km from the Muskingum plant were overpredicted by the model. In fact, the highest concentrations calculated by the model were for these receptors. These were the closest receptors to the plant which were in place during the time period for which this study was done. A close-in receptor has been located about 1 km from the Muskingum plant since that time. The highest observed 1-hour concentrations were at receptors more distant from the source. As was the case for the Canal Plant, there was a tendency to underpredict the 24-hour SO_2 concentrations. At the third plant, Philo, the model substantially overpredicted concentrations at terrain elevations near stack height. This was due primarily to the model procedure that reduces the effective source height above the receptor by an amount equal to the receptor elevation above the stack base. Data for the Canal and Muskingum power plants were further analyzed [9] to determine whether dispersion curves and stability assignment algorithms yielded more accurate results. The Briggs dispersion coefficients [10] did not give significantly better agreement with measured SO_2 hourly concentrations at the Muskingum plant than did the P-G-T coefficients. The Smith-Singer dispersion coefficients [11] and stability assignment method led to a considerable overprediction of 1-hour concentrations at Muskingum. The F. B. Smith coefficients, [12] on the other hand, led to an underprediction of concentrations both with the Turner stability assignment scheme and the F. B. Smith fractional stability algorithm. The underprediction of 1-hour concentrations at the Canal Plant continued to be a problem even with the Briggs and F. B. Smith dispersion parameters. The Smith-Singer curves could not be tested for the Canal Plant since the required "gustiness classes" were not available from on-site data.

In the final model evaluation study of this series, the data for the Canal and Muskingum plants were re-analyzed to allow a comparison of cumulative frequency distributions of measured and calculated 1-hour SO_2 concentrations for different stability classes and different ranges of wind speed and mixing height. The most interesting result of this analysis for Muskingum was the overprediction of concentrations under unstable conditions for the two receptors at 4.3 km and 5.3 km from the plant. On the other hand, the model underpredicted concentrations for these two receptors for the case of neutral stability. This analysis also showed that the highest ratio of predicted to observed concentrations at the Canal Plant occurred for the higher wind speeds. The results of this study showed that a simple comparison of measured and calculated concentration frequency distributions makes it difficult to determine the adequacy of model assumptions, since both measured and calculated distributions might show good agreement and yet the model could be inaccurate when evaluated on a case by case basis. Stated simply, the model could be "right" for the wrong reasons. Under these circumstances one might have less confidence than if the model were to show equally good agreement over a wide range of source-receptor distances. A more meaningful approach would be a comparison of the meteorological characteristics which caused the highest measured and highest calculated concentrations.

The use of monitoring network data for the evaluation of short range dispersion models does present a number of difficulties. While hourly coal consumption on a unit basis can be estimated by use of the hourly megawatt generation, boiler heat rate and average coal heat content, the hourly SO_2 emission rate depends upon the coal sulfur content, which is generally reported only on an "as delivered" basis. It should be noted that the sulfur content measurement is performed on a spot basis so that one would expect less variability in the actual hourly average SO_2 emissions than would be indicated by the spot measurements since such a large quantity of coal is consumed in a single hour. Nevertheless, significant changes in coal sulfur content can occur on a monthly, weekly or even daily basis if coal deliveries are received from different mines or different seams of the same mine. Another problem which must be faced is the limited number of monitors for which continuous concentration data is available. The monitors of a network are generally deployed within a sector of prevailing wind flow with only one or two monitors situated to provide estimates of background concentration. The long period of record for any one monitor does, however, partially compensate for the limited number of monitoring locations. In addition, other problems such as missing data and measurement accuracy must be considered during the model evaluation.

Finally, in this model evaluation procedure, one should not lose sight of the objectives in the development and application of dispersion models. These are the reliable simulation of average and peak concentrations and the assignment of individual source contributions for the development of effective pollution control measures. While these objectives require the use of models which are based upon physically sound assumptions, it should not be necessary to account for every atmospheric process in the greatest possible detail. While a more complex model should in principle be more accurate, this may not always be the case if the critical meteorological conditions are not treated properly or are even ignored, even though other less important conditions are handled in great detail. The introduction of greater complexity in a model, unless warrented by an examination of data, can even produce unwanted noise in the calculation. As a model becomes more complex, its application becomes increasingly difficult due to the increased computing and input data requirements. Even the validation of this type of model becomes rather involved since each of the various components must be properly checked out, a task which is difficult even with large quantities of network or special field monitoring data.

For a given source configuration and geographical location, there will generally be only a few controlling factors in the determination of worst case emissions impact for 3-hour and 24-hour averaging times. These include shoreline fumigation, rough terrain impact under stable conditions, sharp midday concentration peaks during light wind unstable conditions and strong wind neutral stability impacts. A more detailed understanding of these critical meteorological conditions, through the anlaysis of available network data, could be the first step toward the development of simpler and even more realistic dispersion models.

III. DATA BASE DESCRIPTION

A. Network Site Description

As part of the Industrial Coal Use and Electric Utility Simulation Study and the Ohio River Basin Energy Study, the EPA Office of Energy, Minerals and Industry (OEMI) has acquired emissions, meteorological and air quality data from a number of power plant monitoring networks. The major portion of this data base consists of emissions, meteorological and air quality data from the American Electric Power (AEP) and Tennessee Valley Authority (TVA) systems. Initially these data bases were used to better estimate the available air resource for different regions of the country (see Figure III-1). These data were useful for this purpose since they represented continuous gaseous pollutant concentration measurements rather than the daily average values which were often only taken every six days. The hourly SO_2 measurements were required for the identification of 3-hour baseline concentrations. In this initial analysis of the network data, the examination of the spatial and temporal variation of background concentrations was emphasized more than the evaluation of the site specific power plant emissions impacts. To determine the potential for long-range transport at each network location, the tower wind data were screened to find the frequency with which the wind maintains a steady direction at a moderate to high speed. This analysis of background also involved the construction of frequency distributions of hourly SO_2 concentration, wind speed and wind direction for each network monitoring site. When these "pollution roses" were examined, it was found that a number of networks, particularly in the upper Ohio

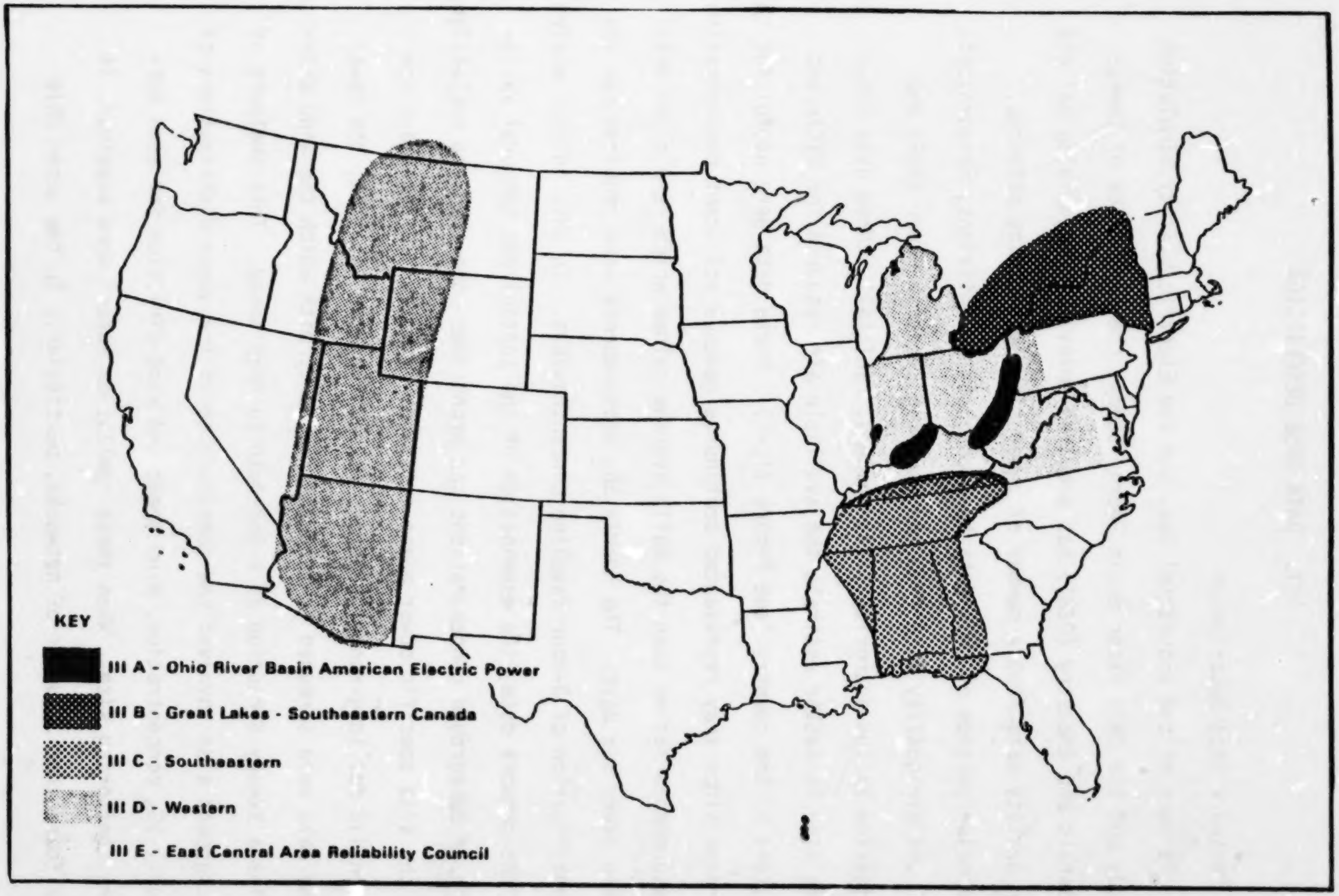

KEY
III A - Ohio River Basin American Electric Power
III B - Great Lakes - Southeastern Canada
III C - Southeastern
III D - Western
III E - East Central Area Reliability Council

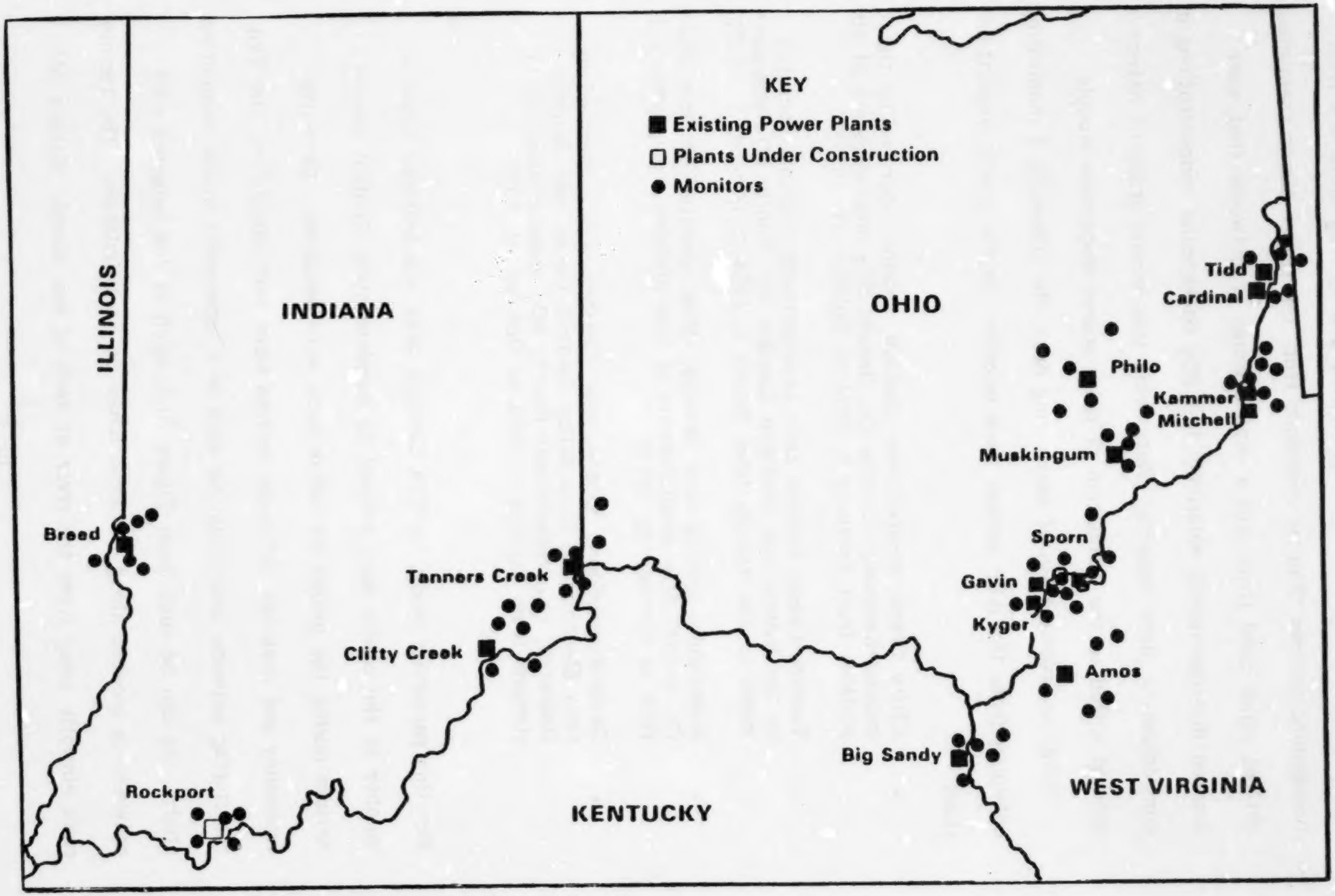
Figure III-1. Regions For Which Continuous Network Monitoring Data Has Been Collected

Valley, appeared to be much more influenced by SO_2 emissions from background sources than by emissions from the power plants themselves. On the other hand there was a second group of networks that were located in areas having relatively low SO_2 background concentrations in comparison to plant impacts. Data from this second group of networks seemed suited to the evaluation of point source dispersion models.

After an examination of monitoring data, the following 4 monitoring networks from the AEP system were selected for the model evaluation study:

- Clifty Creek; located near Madison, Indiana; operated by the Indiana-Kentucky Electric Co. (hourly SO_2 measurements at six stations from February 1, 1974 to October 31, 1977)
- Tanners Creek; located near Lawrenceburg, Indiana; operated by the Indiana and Michigan Electric Co. (hourly SO_2 measurements at six stations from March 1, 1974 to October 31, 1977)
- Muskingum; located near Beverly, Ohio; operated by Ohio Power Co. (hourly SO_2 measurements at four stations from January 1, 1974 to October 31, 1977)
- Gavin-Kyger-Sporn; located near Cheshire, Ohio; operated by Ohio Electric Co, Ohio Valley Electric Co-op, and Central Operating Co., respectively (hourly SO_2 measurements at 11 stations from January 1, 1974 to October 31, 1977)

For this particular study, no TVA network data was included since a number of the plants were subject to Supplementary Control System actions during the period for which data were available. Once the frequency and duration of these actions have been quantified, the TVA monitoring network data could be used in a subsequent model evaluation study. As can be seen from Figure III-2, each of the selected AEP networks is located along the Ohio River or its tributaries. The terrain rises abruptly away from the river at each of the plants. Except for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□ Plants Under Construction
● Monitors
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INDIANA
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WEST VIRGINIA
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Mitchell
Muskingum
Sporn
Gavin
Kyger
Amos
Big Sandy
Tanners Creek
Clifty Creek
Breed
Rockport

Figure III-2. Locations of AEP Monitoring Networks

the 3 low stacks at the Tanners Creek Plant, which were in place until 1977, the terrain is below the actual stack tops at each of the networks. The monitor and stack base elevations for the Clifty Creek and Tanners Creek networks are given in Table III-1(a) along with the location of each monitor with respect to the plant. Locations and elevations of stacks and monitors for the Muskingum and Gavin-Kyger-Sporn networks are given in Table III-1(b). In general, the areas around the networks are characterized by a mixture of woods and farmland with a roughness of approximately 20cm.

B. Emissions Data

The first source of emissions data for the 6 power plants considered in this model evaluation study was Federal Power Commission (FPC) Form 67. This gives a monthly account of coal usage for each of the power plant boilers in addition to average fuel sulfur content on a monthly basis for the plant as a whole. FPC Form 67 also gives information as to stack height, stack diameter, gas exit velocity and gas exit temperature in addition to specifying the correspondence between stacks and boilers at the plant. The monthly coal sulfur content for each plant for the years 1974-1977 is given in Table III-2. Monthly average power plant emission rates of SO_2 during this period are presented in Table III-3. These monthly average SO_2 emissions rates were calculated from FPC Form 67 reported monthly sulfur content and coal consumption. The boiler characteristics for each of the plants are given in Table III-4. At the outset of this project it was decided that hourly estimates of coal consumption at each boiler would be based upon monthly average coal heat content, boiler heat rates and hourly megawatt genera-

Table III-1(a)

Location and Elevation of Network Monitors and Plant Sites for Single Source Model Runs

Plant	Site	Distance from the plant(km)	Heading toward the plant(degrees from north)	Elevation MSL(meters)
Clifty Creek		-	-	143
	Bacon Ridge	15.0	220	277
	Rykers Ridge	7.4	236	274
	North Madison	4.5	196	267
	Hebron Church	11.6	204	273
	Liberty Ridge	3.1	354	253
	Canip Creek	8.0	279	146
Tanners Creek		-	-	151
	Dutch Hollow	5.8	43	247
	Petersburg	3.7	29	155
	Wilson Creek	3.9	147	247
	Lawrenceburg	1.4	199	142
	Elizabethtown	9.8	209	152
	Kilby Road	16.1	204	157

Table III-1(b)

Location and Elevation of Network Monitors and Plant Sites for Multiple Source Model Runs

Network	Source	Site	X(km)	Y(km)	Elevation MSL(meters)
Muskingum					
	Muskingum 1		0.0	0.0	196
	Muskingum 2		-0.549	-0.305	203
		M1[a]	0.643	0.766	274
		M2	0.964	1.149	256
		M3	1.286	1.532	256
		M4	1.608	1.915	244
		M5	1.929	2.298	256
		Hackney	2.791	3.324	274
		Beverly	3.413	-4.068	256
		Rich Valley	4.617	6.594	305
		M6	7.716	9.192	299
		Caldwell	11.351	16.211	332

[a] Monitors M1-M6 refer to the six additional receptors used in the model runs for Muskingum.

Table III-1(b) Continued

Network	Source	Site	X(km)	Y(km)	Elevation MSL(meters)
Gavin-Kyger-Sporn					
	Kyger 1		-0.871	-2.671	176
	Kyger 2		-0.911	-2.647	176
	Kyger 3		-0.956	-2.620	176
	Sporn 1		16.939	2.987	179
	Sporn 2		16.897	3.186	179
	Gavin		0.0	0.0	173
		Henderson	2.605	-14.772	170
		Lakin	3.323	3.323	183
		Wolfpen	2.767	14.234	274
		Mason	8.776	8.475	195
		New Haven	11.693	0.408	244
		Mt. Alto	17.321	-9.999	283
		Five Points	14.142	14.142	244
		Dorcas	23.559	4.579	219
		Coolville	25.004	29.799	244
		Neptune	30.878	13.748	277
		Kerr	-11.386	-3.481	259

Table III-2

Monthly Average Percent Sulfur Content for the 6 AEP Plants

Plant-year / Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clifty Creek	-1974	3.7	3.7	3.3	3.3	3.9	3.7	4.0	3.8	3.3	3.6	3.8	3.6
	1975	3.8	3.7	3.6	3.5	3.2	2.8	3.7	3.4	3.2	3.4	3.4	3.5
	1976	3.5	3.3	3.5	3.6	3.4	3.4	3.7	3.4	3.6	3.6	3.5	3.6
	1977	3.5	3.5	3.4	3.8	3.8	3.9	4.0	3.7	4.0	4.0	4.0	4.0
Tanners Creek	-1974	3.6	3.7	3.4	3.3	3.7	3.7	2.6	3.3	3.2	3.5	2.6	3.8
	1975	3.8	3.8	3.6	3.4	3.2	3.4	3.8	3.8	4.2	4.0	4.1	3.4
	1976	2.6	2.7	3.2	3.4	3.0	3.9	4.2	4.0	3.7	4.2	4.4	2.1
	1977	3.7	2.4	3.6	4.0	3.8	4.3	3.4	3.3	4.0	3.9	3.9	2.3
Muskingum	-1974	4.6	4.3	5.2	5.0	5.2	5.4	5.5	5.1	5.6	5.2	5.0	4.1
	1975	4.6	3.9	4.1	4.8	4.7	4.7	4.1	4.5	4.6	4.7	4.9	4.8
	1976	4.5	4.5	4.6	4.9	5.1	5.4	5.3	5.1	5.4	5.1	5.2	4.9
	1977	4.9	4.9	4.4	4.4	4.5	4.8	4.6	4.4	4.6	4.9	5.1	4.6
Gavin	-1974	-	-	-	-	-	-	-	-	-	2.1	2.4	2.1
	1975	2.3	2.6	2.7	2.6	2.8	2.6	2.0	2.4	2.5	2.5	2.6	2.7
	1976	2.8	2.6	2.3	2.2	2.6	2.9	2.6	2.2	2.3	2.0	1.6	2.3
	1977	2.5	2.6	2.0	2.1	1.7	1.9	1.9	1.6	1.6	1.8	2.1	1.5
Kyger	-1974	3.8	3.9	4.0	3.7	3.8	3.7	3.8	3.6	4.0	4.0	4.0	4.2
	1975	4.1	3.9	3.9	4.1	4.0	4.1	4.1	4.2	4.3	4.3	4.2	4.2
	1976	4.1	4.2	4.2	4.1	4.2	4.2	4.2	4.6	4.2	4.1	4.1	4.3
	1977	4.1	4.0	4.1	3.9	3.9	4.0	4.0	4.2	4.1	4.1	4.0	4.0
Sporn	-1974	1.4	1.3	1.4	1.6	1.3	1.8	1.4	1.2	1.3	1.2	1.4	1.4
	1975	1.3	1.2	1.8	1.5	1.2	1.2	1.2	1.2	1.1	1.2	1.1	1.1
	1976	1.1	1.0	.9	1.0	1.1	.9	.9	.9	.9	.9	.9	1.0
	1977	1.0	.9	1.0	.9	.8	1.0	.9	1.0	1.0	1.0	.9	1.0

Table III-3

Monthly Average SO_2 Emission Rates (g/s) for the 6 AEP Plants

Plant	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Clifty Creek	1974	9946	8392	8570	693	-	570	6608	9416	9337	9752	9204	7560	7277
	1975	9709	8262	9173	8796	6518	7154	9350	8592	7706	8473	8758	8722	8434
	1976	8016	8080	8526	8648	7997	8858	9530	9405	8996	9834	9601	9445	8911
	1977	7967	7651	8187	9062	9157	8274	10171	9084	8708	10220	9849	9441	8981
	Ave	8564	7998	8629	8835	7891	8095	9684	9027	8470	9509	9403	9203	8401
Tanners Creek	1974	5590	4311	4869	4629	6375	4459	3807	5099	4107	4737	3915	6136	4836
	1975	4674	4014	5087	3492	3497	3417	4075	6000	5784	4350	4776	5607	4564
	1976	3905	2523	4663	5102	2414	5614	5148	4970	3966	4796	4391	1846	4112
	1977	3257	2762	6062	5425	4763	5554	4376	4320	3930	3221	3530	3155	4196
	Ave	4356	3402	5170	4662	4262	4761	4352	5097	4447	4276	4153	4186	4427
Muskingum	1974	11157	8663	10126	11662	12382	13192	12996	9928	10219	9669	7720	8386	10508
	1975	9148	7284	8527	7809	9985	8949	9589	9774	7013	10084	9703	6646	8709
	1976	10420	9368	10394	10897	11428	10584	10481	10274	11529	8529	7822	11343	10256
	1977	13072	11223	11353	9945	8959	11726	11569	7685	9035	10290	7611	9171	10137
	Ave	10949	9134	10100	10078	10688	11113	11159	9415	9449	9643	8214	8886	9902
Gavin	1974	-	-	-	-	-	-	-	-	-	2319	5018	5179	-
	1975	6422	1454	4632	7722	7274	9400	8676	11627	10944	11070	9533	12043	8400
	1976	13206	10713	8896	6504	13516	9300	11055	9776	11150	9697	8770	10713	10275
	1977	12140	12194	4956	6051	6738	8750	9622	8435	8634	7882	10373	7444	8602
	Ave	10589	8120	6161	6759	9176	9150	9784	9946	10243	9550	9559	10067	9092
Kyger	1974	6677	7207	7476	7848	8379	7459	7767	7812	6692	7644	8456	8761	7682
	1975	6687	6962	7426	5769	8316	7864	7175	8879	8187	8368	8526	9114	7773
	1976	8625	6762	8458	7129	8932	8866	7233	8586	8573	8412	8288	9132	8250
	1977	9425	7296	7365	7088	6684	8316	7932	8429	7892	7470	6799	8448	7762
	Ave	7854	7057	7681	6958	8078	8126	7527	8426	7836	7974	8017	8864	7867
Sporn	1974	2181	1821	2471	1481	1994	2972	2201	1683	1581	1275	2023	2214	1991
	1975	1659	1515	2560	1420	613	1342	667	1056	498	697	1304	1384	1226
	1976	1679	1014	1150	1524	1555	787	1057	994	845	690	878	1125	1108
	1977	1432	1344	1127	1038	1006	1213	1043	1307	797	793	673	692	1039
	Ave	1738	1424	1827	1366	1292	1578	1242	1260	930	864	1220	1354	1341

Table III-4

Boiler Characteristics for the 6 AEP Power Plants

Plant	Boiler *	Capacity (MW)	Fuel Use Regression Relationship	
			Slope $\left(\frac{1000\ \text{tons}}{\text{month MW}}\right)$	Intercept $\left(\frac{1000\ \text{tons}}{\text{month}}\right)$
Clifty Creek	1	217.26	0.3042	-0.3239
	2	217.26	0.2910	0.5976
	3	217.26	0.2935	0.2132
	4	217.26	0.2952	-0.0656
	5	217.26	0.2963	-0.0828
	6	217.26	0.2952	0.1327
Tanners Creek	1	135.38	0.3077	-0.1214
	2	135.38	0.3035	-0.6925
	3	213.00	0.2943	-0.6628
	4	546.24	0.3016	1.0900
Muskingum	1	213.00	0.3310	-0.0167
	2	213.00	0.3255	0.9636
	3	225.00	0.3229	1.4860
	4	225.00	0.3300	0.0049
	5	590.80	0.3088	-0.0579
Gavin	1	1300.00	0.3344	-4.0350
	2	1300.00	0.3250	-0.0770
Kyger	1	217.26	0.2948	0.0313
	2	217.26	0.3051	0.1061
	3	217.26	0.2987	-0.0003
	4	217.26	0.3024	-0.0434
	5	217.26	0.2975	0.1935
Sporn	1	152.5	0.2938	-0.0683
	2	152.5	0.3004	0.0153
	3	152.5	0.2802	0.2516
	4	152.5	0.2881	-0.4050
	5	450.0	0.2816	-0.9340

tion. The values of hourly megawatt generation for each power plant unit were provided by AEP on the same tape which contained the air quality and meteorological data. Later it was found that the boiler heat rate information was not necessary since an excellent correlation was obtained between monthly average megawatt generation and total monthly coal consumption at a particular unit. The slope and intercept of the line relating megawatt generation to the coal consumption rate in 1000 tons/month is given in Table III-4 for each unit at the 6 AEP plants. The high correlation (generally greater than 0.95) found between coal consumption and megawatt generation is not surprising since the heat content of the coal shows only a slight variation on a monthly or even yearly basis.

The selection of stack parameters for modeling, especially the gas exit velocities and temperatures, presented more of a problem, since information obtained from EPA Regional Offices and state agencies was at odds with that taken from FPC Form 67. Conversations with AEP personnel revealed that the gas exit velocities reported in FPC Form 67 were systematically overestimated. Final emission parameters used for the modeling were primarily obtained from AEP Service Corporation, which had gathered this information from its member utilities. These stack parameters are presented in Table III-5. The SO_2 emission rate quoted for each stack is an average over the period 1974-1977, except for the Tanners Creek plant which underwent a major change in stack configuration during 1977. Emissions quoted in Table III-5 for this plant are the average for 1974-1976.

The SO_2 emission rate, gas exit temperature and gas exit velocities are estimated for each hour based upon the percent load for each

Table III-5

Stack Parameters for the 6 AEP Power Plants

					Stack Gas Temperature(°K)			Gas Exit Velocity(m/s)			
Plant	Stack Number	Emission Rate(g/s)	Stack Height(m)	Stack Diameter(m)	100 load	75 load	50 load	100 load	75 load	50 load	Boilers Served
Clifty Creek	1	2721	207.87	4.63	445.37	445.37	445.37	49.9	37.42	24.95	1,2
	2	2873	207.87	4.63	445.37	445.37	445.37	49.9	37.42	24.95	3,4
	3	2806	207.87	4.63	445.37	445.37	445.37	49.9	37.42	24.95	5,6
Tanners Creek[a]	1	636	83.21	3.58	444.26	444.26	444.26	26.0	19.51	10.18	1
	2	727	83.21	3.58	444.26	444.26	444.26	26.0	19.51	10.18	2
	3	853	83.21	4.47	444.26	444.26	444.26	23.87	17.89	11.95	3
	4	2293	167.64	5.41	444.26	444.26	444.26	36.88	27.74	18.44	4
Muskingum	1	5981	252.4	7.62	430.37	430.37	430.37	34.47	25.85	17.24	1,2,3,4
	2	3921	252.4	6.71	432.04	427.59	420.93	23.16	17.37	11.58	5
Gavin	1	9092	335.9	12.95	444.26	444.26	444.26	31.88	23.91	15.94	1,2
Kyger	1	3123	164.0	4.44	435.93	435.93	435.93	52.55	39.41	26.28	1,2
	2	1526	164.0	3.15	435.93	435.93	435.93	52.36	39.27	26.18	3
	3	3218	164.0	4.44	435.93	435.93	435.93	52.55	39.41	26.28	4,5
Sporn	1	784	182.88	6.56	422.04	422.04	422.04	23.83	17.87	11.92	1,2,3,4
	2	556	183.34	4.60	422.04	422.04	422.04	36.11	27.08	18.06	5

[a] This stack configuration is only for the period 1974-1976

boiler and the average monthly sulfur content of the coal. If the ratio of the total hourly megawatt generation to the total capacity for all boilers feeding into a particular stack is greater than 0.5, the hourly values for exit velocity and temperature are obtained through linear interpolation of the 100, 75 and 50 percent load values given in Table III-5. For all stacks except the second stack at Muskingum, the gas temperature did not vary with load. If this load factor is less than 0.5, the 50 percent load values are selected. This assumption was made to avoid the calculation of unrealistically high concentrations for a short period during which all the boilers served by a particular stack are being shut down. The hourly SO_2 emission rate for each stack is the sum of the emissions from each unit, which are calculated from the individual megawatt loadings using the regression parameters given in Table III-4 and the monthly coal sulfur contents given in Table III-2. Again it should be pointed out that this SO_2 emissions data base does not reflect the variation of coal sulfur content on a daily or hourly basis.

C. Meteorological Data

The meteorological data used in this point source model evaluation study was derived from three sources: (1) on-site tower and surface wind speed, wind direction and ambient temperature data; (2) surface observations from the nearest National Weather Service (NWS) locations; and (3) morning and afternoon mixing heights obtained from temperature soundings taken at NWS upper air stations. The first step in the meteorological analysis was the input of surface and upper air data into the CRSTER meteorological preprocessor program[1]. Hourly stability class assignments are made upon the basis of calculated solar elevation angle and reported values of wind speed, ceiling height and fractional cloud cover. For each hour a wind flow vector is also determined by taking the reported wind direction (specified to the nearest 10 degrees), adding 180 degrees and then using a randomization procedure to specify a value to the nearest degree. Hourly mixing heights are calculated from morning and afternoon values by means of the stability dependent interpolation scheme shown in Figure III-3. Note that for the rural case, which pertains to the 4 networks used in this study, only the afternoon mixing heights are used for the estimation of hourly mixing heights. For this study, rural mixing heights were used for each of the four networks. In some cases the morning or afternoon mixing heights were missing or not calculated due to cold air advection or precipitation. To provide a continuity of data for the model simulation, these missing observations were replaced by values obtained through an interpolation of the preceeding and following day's values. For the Clifty Creek and Tanners Creek networks, surface meteorological data from Cincinnati, Ohio and upper air data from Dayton, Ohio for the years 1974-1977 were selected for input to the preprocessor program. For the Muskingum and Gavin-Kyger-Sporn networks, the surface data was from Parkersburg, W. VA and the upper air data from Huntington, W. VA.

For the Clifty Creek and Tanners Creek plants, on-site wind and temperature data were substituted for the corresponding preprocessor output parameters so that the model input data would be more representative of the actual network locations. The wind speed measured at the 60 meter tower level is adjusted to the 7 meter level (assumed for airport wind measurements) by use of the stability dependent wind

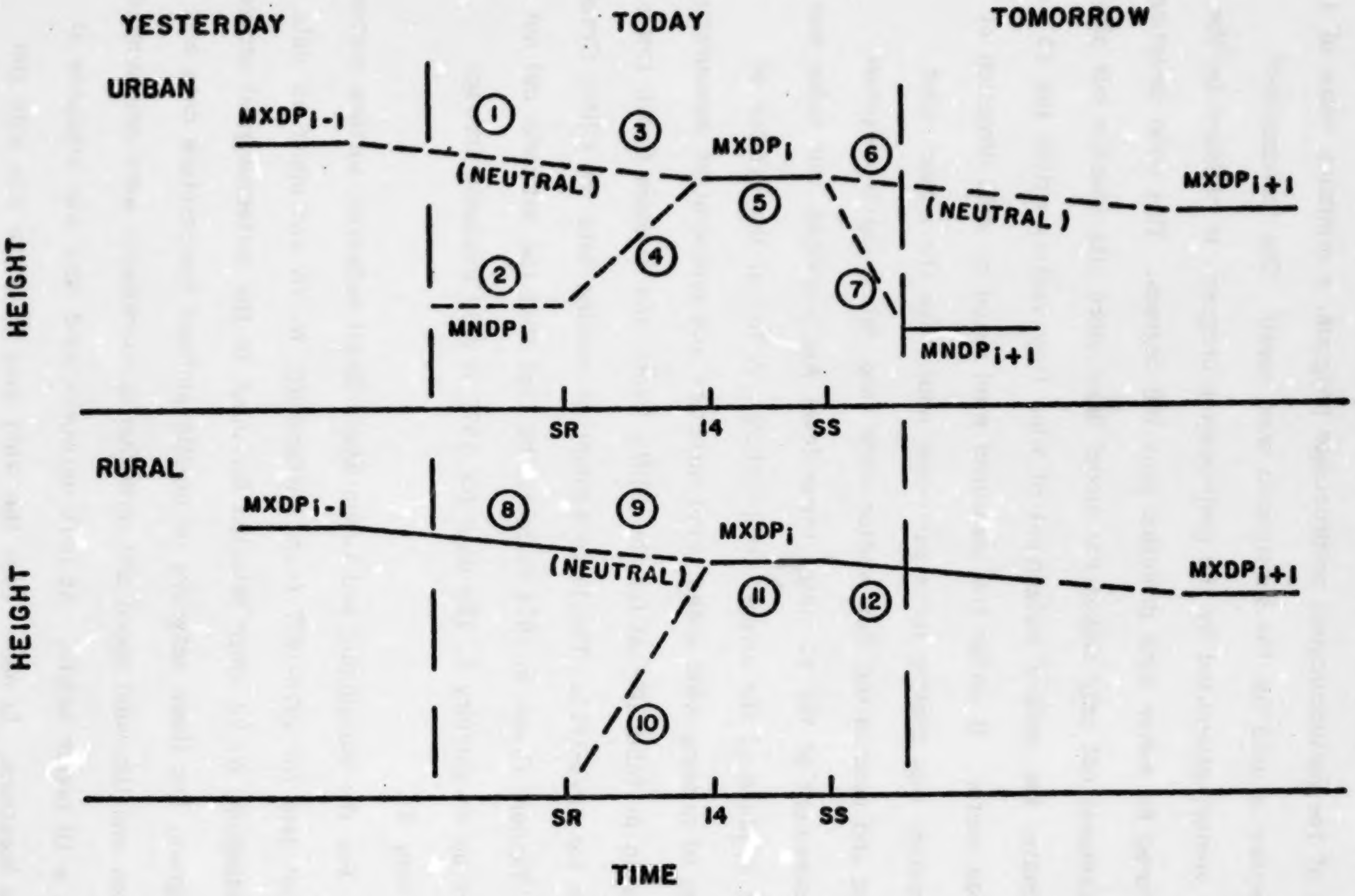

YESTERDAY
TODAY
TOMORROW
URBAN
MXDP$_{i-1}$
(NEUTRAL)
MXDP$_i$
(NEUTRAL)
MXDP$_{i+1}$
MNDP$_i$
MNDP$_{i+1}$
①
②
③
④
⑤
⑥
⑦
HEIGHT
SR
14
SS
RURAL
MXDP$_{i-1}$
(NEUTRAL)
MXDP$_i$
MXDP$_{i+1}$
⑧
⑨
⑩
⑪
⑫
HEIGHT
SR
14
SS
TIME

Figure III-3. Determination of hourly mixing heights

profile coefficients given in Table III-6. In accordance with the assumptions of the meteorological preprocessor program, a minimum value of 1 meter/sec is used for the substituted wind speed. The "randomized" flow vector, calculated by the preprocessor program, is replaced by the measured 60 meter wind direction plus 180 degrees. This wind direction replacement not only makes the model input more site specific but also eliminates the random assignment of wind flow vectors within the 10 degree sector. If either the measured wind speed or wind direction at 60 meters was missing for a particular hour, then the airport wind speed and randomized flow vector were used. When the temperature measurement at the 10 meter tower level was available, this value was used in place of the airport temperature. A list of the number of hours of missing wind speed, wind direction and temperature measurements is given in Table III-7(a) for the Clifty Creek and Tanners Creek tower sites for 1974-1977. The large amount of missing data for Clifty Creek and Tanners Creek in 1974 reflects the fact that the networks did not start up on January 1. The data for 1977 is only available through October 31.

For the Muskingum and Gavin-Kyger-Sporn networks, surface meteorological data for 1974-1977 from Parkersburg, W. VA and upper air data from Huntington, W. VA were selected for input to the meteorological preprocessor program. For these networks no on-site ambient temperature data was taken and the wind speed and direction measurements were only available for a 10 meter height. At both networks wind data was available at two locations. In each case the wind data from the site with the greatest elevation was selected for substitution into the preprocessor

Table III-6

Turner and Irwin Power Law Wind Profile Coefficients for Stabilities (1-6)

Stability Class	Power Law Coefficient (α)	
	Turner	Irwin (20cm roughness)
1	0.1	0.10
2	0.15	0.11
3	0.2	0.12
4	0.25	0.19
5	0.3	0.26
6	0.3	0.42

$$u_h = u_{7\text{ meters}} \left(\frac{h}{7\text{ meters}} \right)^{\alpha}$$

h = height above ground (meters)

Table III-7(a)

Inventory of Missing Wind Speed, Wind Direction and Temperature Measurements at the Clifty Creek and Tanners Creek Tower Sites

		Percentage of Missing Hours		
Network	Year	Wind Speed	Wind Direction	Temperature
Clifty Creek	1974	40.6	37.6	38.6
	1975	11.3	6.4	6.4
	1976	1.1	0.7	0.5
	1977	17.4	16.8	16.8
Tanners Creek	1974	29.5	29.1	26.8
	1975	1.6	<0.1	0.2
	1976	2.4	1.9	0.4
	1977	17.5	17.2	17.6

Table III-7(b)

Inventory of Missing Wind Speed and Wind Direction Measurements at the Muskingum and Gavin-Kyger-Sporn Surface Sites

		Percentage of Missing Hours	
Network	Year	Wind Speed	Wind Direction
Muskingum	1974	5.1	4.0
(Hackney)	1975	0.5	0.5
	1976	1.0	0.1
	1977	17.0	17.3
Gavin-Kyger-	1974	23.6	22.8
Sporn	1975	0.6	0.4
(Mt. Alto)	1976	5.5	18.5
	1977	17.7	21.9

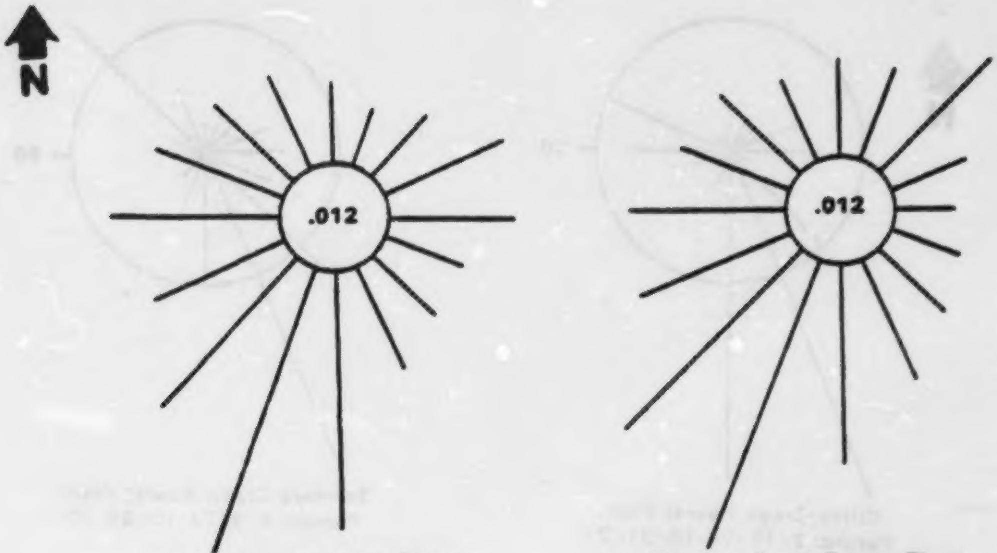
output. An inventory of missing wind speed and direction measurements for these networks is given in Table III-7(b). In the final model runs for Muskingum and Gavin-Kyger-Sporn, the on-site wind data was, however, not used since it was discovered that for very light winds, the trailer-top wind direction measurement gave the same value to the nearest degree, for the duration of a light wind condition. The meteorological preprocessor output data for Parkersburg-Huntington was used instead to avoid this problem of artificial directional persistence during light wind conditions.

At the Clifty Creek and Tanners Creek networks the wind speed at the 60 meter tower level is measured with a Climet Model 011-1 transmitter with a Climet Model D800A-6 translator card. The transmitter has a starting threshold of 0.6 mi/hr and an accuracy of ±1 percent. The wind system is operated in the 0-50 mi/hr range. The wind direction system consists of a Climet Model 012-10 transmitter and a Model C-8091-1 translator card. The transmitter has a starting threshold of 0.75 mi/hr and an accuracy of ±3 degrees. Ambient temperature is measured at the 10 meter level using a Climet Model 015-3x2 thermistor and a Model D-8004-32 translator card. The temperature sensor has a range of -30°C to +50°C and an accuracy of ±0.15°C. The temperature difference between the 60 meter and 10 meter tower levels is measured with a pair of selected Climet Model 015-3/2 thermistors. Although the temperature difference measurement is not used as input to the dispersion models, it appears to be an indicator of plume impact during midday unstable conditions.

The ground wind stations at the Muskingum and Gavin-Kyger-Sporn networks use a Bendix Aerovane Model 120. The wind speed starting threshold is 2.5 mi/hr and the accuracy is 5 percent for wind speeds over 10 mi/hr. The accuracy of the wind direction measurement is <± 5 degrees. It should be noted that since the reported 1-hour meteorological parameters are based upon an average of values sampled every two minutes, these 1-hour averages should have a smaller error than those quoted for the instantaneous measurements, except in the case of a systematic bias in the readings.

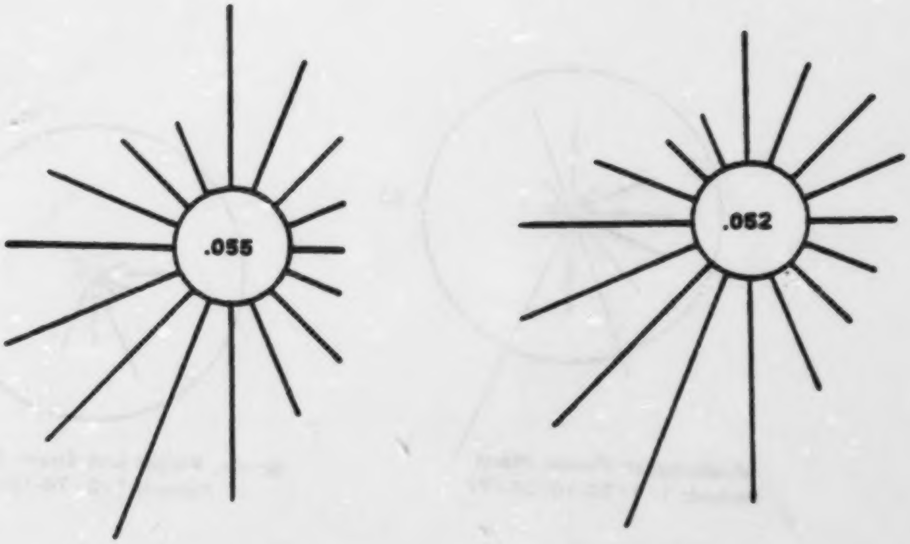
An initial analysis of the meteorological data for the 4 AEP networks was carried out to gain some understanding of the site specific dispersion characteristics. The relative frequency of wind directions at each of the networks is shown in Figure III-4. The "wind roses" for the Clifty Creek and Tanners Creek plants are based upon 60 meter winds while the Muskingum and Gavin-Kyger-Sporn results are based upon ground level (10 meter) winds. The prevailing wind direction at all 4 networks is south-southwest. The south-southwest winds during the winter months occur to the rear of a cold high pressure system passing off the east coast. An extension of the Bermuda high into the south-eastern states is responsible for the south-southwest winds during the summer. This south-southwest component is also evident when the number of cases of extremely persistent winds are displayed for each network as a function of wind direction (see Figure III-5). In Table III-8 the percent occurrence of the 7 stability classes is given for both the Cincinnati and Parkersburg NWS sites for the years 1974-1977. For both these sites the frequency of stability class A (extremely unstable) is quite small and shows considerable variation from one year to the next. For the CRSTER (Turner) Model this stability class often represents the critical meteorological condition for the highest 3-hour impact. The frequency of occurrence

Figure III-4. Relative Frequency of Wind Directions at the 4 AEP Networks[a]



Clifty Creek Power Plant
Period: 3/19/74-10/31/77

Tanners Creek Power Plant
Period: 4/3/74-10/31/77

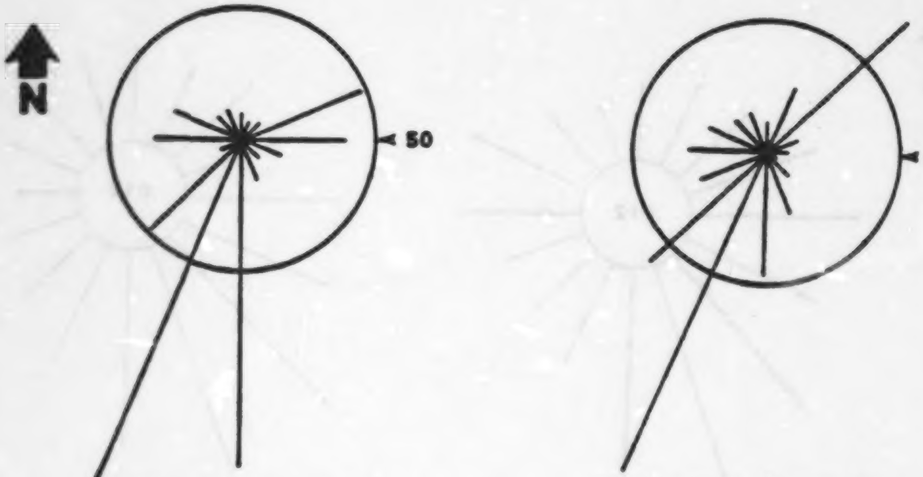


Muskingum Power Plant
Period: 1/1/74-10/31/77

Gavin, Kyger and Sporn Power Plants
Period: 1/1/74-12/31/75

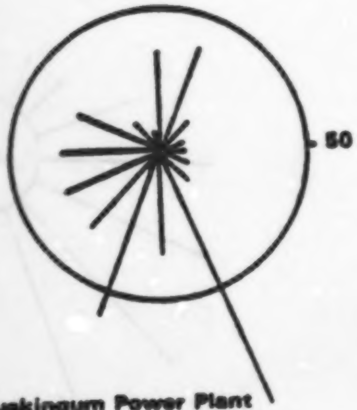
[a] Number in the center of the figures refers to the fraction of observations of calm winds

Figure III-5. Number of Cases of Extremely Persistent Winds at the 4 AEP Networks [a]

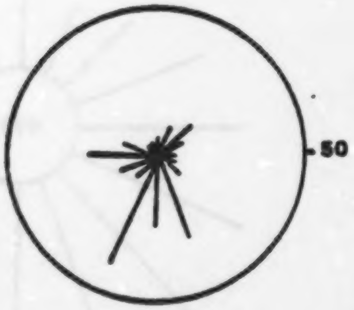


Clifty Creek Power Plant
Period: 3/19/74-10/31/77

Tanners Creek Power Plant
Period: 4/3/74-10/31/77



Muskingum Power Plant
Period: 1/1/74-10/31/77



Gavin, Kyger and Sporn Power Plants
Period: 1/2/74-12/31/75

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[a] A Period of extreme persistence is said to occur when the on-site wind direction does not vary by more than 11 degrees and the wind speed by more than 2.5 m/sec for 7 consecutive hours.

Table III-8

Frequency of Turner Stability Classes for the Cincinnati and Parkersburg NWS Stations

Site	Year	Percent Occurrence A	B	C	D	E	F	G
Cincinnati	1974	0.73	4.83	10.83	55.71	13.49	10.28	4.68
	1975	0.58	4.90	11.18	53.37	13.33	10.98	5.65
	1976	0.48	4.27	11.48	51.43	13.94	11.34	7.02
	1977	0.58	4.17	10.96	54.69	13.93	10.75	4.92
Parkersburg	1974	0.82	4.81	11.14	52.43	11.79	12.74	6.27
	1975	0.92	5.38	11.55	50.81	12.68	13.92	4.74
	1976	0.65	4.58	11.30	50.93	14.02	13.93	4.55
	1977	1.24	5.89	11.93	44.92	13.20	13.94	8.89

of different wind speed classes is shown in Table III-9. At each of the networks there appears to have been a greater frequency of low wind speeds in 1975, especially at the Muskingum network.

D. Air Quality Data

At each of the 4 AEP networks used for this model evaluation study, some or all of the following air quality parameters are measured: CO, SO_2, NO_2, NO_x, NO, O_3, visibility and coefficient of haze. For this study the only air quality parameter considered was the hourly SO_2 concentration measured at the network sites. As was the case for the meteorological parameters, the reported hourly SO_2 concentrations are based on an average of values sampled every two minutes. Except for the Muskingum network during 1974-1975, SO_2 concentrations were measured with the Meloy SA185-2 which employs the flame photometric technique. The manufacturer's specifications for the Meloy instrument are as follows:

Range	0-1 ppm
Sensitivity	0.005 ppm
Noise	±0.5 percent
Response Lag	< 15 seconds
Rise time to 90 percent	< 30 seconds
Fall time to 90 percent	< 30 seconds
Precision	±1 percent Full Scale
Accuracy	±1 percent Full Scale
Zero drift	±0.02 ppm/3 days
Span drift	±0.01 ppm/day ±0.02 ppm/3 days
Linearity	1 percent Full Scale

The zero and span drifts for this instrument were adjusted daily. During the period 1974-1975 at the Muskingum network, SO_2 concentrations

Table III-9

Frequency of Wind Speeds[a] for the AEP Networks

Network	Year	0- 1.80m/s (0-3knots)	1.80- 3.34m/s (4-6knots)	3.34- 5.40m/s (7-10knots)	5.40- 8.48m/s (11-16knots)	8.48- 10.79m/s (17-21knots)	10.79m/s- (22+knots)
Clifty Creek	1974	19.79	40.42	26.92	11.27	1.26	0.34
	1975	21.77	48.15	23.35	6.11	0.54	0.08
	1976	18.98	49.57	27.85	3.53	0.03	0
	1977	19.58	48.07	24.63	7.17	0.49	0.06
Tanners Creek	1974	20.34	42.02	26.63	9.77	0.89	0.34
	1975	25.09	48.26	21.56	4.95	0.13	0
	1976	20.59	46.97	26.88	5.06	0.35	0.11
	1977	20.89	45.32	25.50	7.72	0.51	0.06
Muskingum	1974	28.01	44.41	21.52	5.49	0.50	0.06
	1975	43.57	36.74	14.42	4.90	0.33	0.03
	1976	28.31	38.90	23.85	8.24	0.59	0.07
	1977	29.16	41.45	22.14	6.59	0.65	0
Gavin - Kyger-Sporn	1974	22.03	39.24	31.07	7.31	0.33	0.01
	1975	26.87	40.35	25.19	6.90	0.58	0.10
	1976	20.03	39.62	30.80	9.05	0.40	0.06
	1977	23.22	40.21	28.49	7.23	0.70	0.15

[a] Adjusted to the 7 meter level by use of the CRSTER (Turner) wind profile (see Table III-6).

were measured with Leeds and Northrup Aeroscan Monitors (#7860-SW). The manufacturer's performance specifications for this instrument, for an ambient atmosphere with typical interfering gases, are as follows:

Zero drift = 2 percent of full scale per week
Sensitivity drift $<$ 1 percent of full scale per week
Reproducibility $<$ 1 percent of full scale
Sensitivity = 0.01 ppm
Recorder error = 0.5 percent of full scale
Range = approximately 0-1 ppm

Obviously the quality of this SO_2 data depends not only upon the accuracy of the instrument, but also upon the procedures for checking and calibration and whether they were indeed followed. A comprehensive set of quality assurance procedures has been developed for handling these data by AEP's monitoring consultant, Environmental Research and Technology (ERT). Even the best designed quality assurance program, however, cannot anticipate every possible source of monitoring error. A discussion of the realities of monitoring network design and operation was presented by ERT at a recent Air Pollution Control Association (APCA) specialty conference[13] dealing with quality assurance. One problem mentioned in this paper is related to a small portion of the SO_2 data used for this current model evaluation study. From November 1976 to July 1977 a molecular sieve ("heatless dryer") was used in the laboratories for the removal of moisture from the gases used to calibrate the Meloy instrument. Unfortunately this procedure also resulted in the removal of some of the ambient CO_2 from the calibration gas. Since CO_2 normally interferes with SO_2, this caused an underestimate of ambient SO_2 concentrations by up to 16 percent for values greater than about 80 $\mu g/m^3$ during this brief period. Concentrations below this value were actually overestimated, so that the annual average concentration was affected to a much lesser degree. These types of uncertainties in the SO_2 concentration measurements, if they were extensive in time, would be more serious in the portion of the study involving a quantitative comparison of measured and calculated concentrations. In other portions, where the concentrations are used principally as an indication of when and where significant 3-hour and 24-hour concentrations are observed so that the meteorological characteristics of these periods can be compared with those associated with the highest calculated concentrations, it would be of less concern.

Before the model evaluation study was begun, an analysis of the hourly SO_2 concentrations was performed to examine the relationship between these concentrations at each network site and on-site meteorological parameters such as wind speed and direction. Of particular interest is the average SO_2 concentration at each site as a function of wind direction. These "pollution roses" can identify the average contribution of the plant relative to background sources. For this reason they were helpful in making the decision as to which of the 4 networks would be used in the model evaluation study.

IV. DISPERSION MODEL DESCRIPTIONS

A. Sequential Gaussian Modeling Approach

National Ambient Air Quality Standards (NAAQS) and Standards for the Prevention of Significant Deterioration (PSD) for short term concentrations are expressed in terms of values which may be exceeded only once per year. For this reason, most of the models developed by EPA for regulatory purposes (CRSTER,[1] RAM,[31] MPTER[32]) have been designed to operate on a sequential hourly basis. For each hour of the year a concentration is calculated for each receptor location by use of the steady-state gaussian plume model using hourly meteorological input data. In the compliance analysis for SO_2, the highest calculated 3-hour and 24-hour SO_2 concentrations at each receptor are discarded and the next highest concentrations are examined to find the value and location of the "highest, second-highest" 3-hour and 24-hour concentrations.

This sequential modeling approach has some obvious limitations. The models are designed only to deal with steady state conditions over a one-hour period, a definite drawback when one is trying to simulate midday concentration impacts under light wind conditions. For tall stack power plants in rural areas, this is often found to be the critical meteorological condition for the 3-hour averaging time. In some sense the models do include this unsteady condition by their use of vertical and horizontal dispersion curves for the extremely unstable (A) and moderately unstable (B) stability classes. For near calm winds, however, even the concept of a definable plume may be inappropriate. Furthermore, the steady state assumption implies that the plume concentration profile is established out to some infinite distance, whereas the limiting range actually would correspond to the air parcel travel distance for that hour or as long as the conditions persist. While the models do assume a steady state condition during a particular hour, there is an abrupt change in the calculated concentration pattern for the next hour in response to the input of a different set of meteorological conditions. An examination of hourly SO_2 concentrations around power plants shows that there is a more gradual variation of concentrations from one hour to the next. In spite of these drawbacks, the sequential gaussian models have the advantage that they are easily implemented by state and local agencies and only require routine meteorological observations for input.

As stated in Section I, two versions of the EPA CRSTER Model, CRSTER (Turner) and CRSTER (Irwin), were evaluated in this study. CRSTER (Turner) is the current EPA CRSTER Model. CRSTER (Irwin) is a modification of the model based upon Irwin's horizontal and vertical dispersion curves. These models differ only in the choice of horizontal and vertical plume dispersion coefficients (σ_y and σ_z) and wind profile coefficients. Before dealing with the differences between the Turner and Irwin schemes, the basic sequential modeling approach used in CRSTER will be described.

The CRSTER Model uses the output of the meteorological preprocessor program, mentioned in the previous section, to calculate hourly, daily and annual pollutant concentrations at 180 receptor locations situated at each of 36 directions from the source at 5 distance ranges. The model can handle from 1 to 19 sources, but treats all of them as if they were at the same physical location. The expression used for calculation of ground level 1-hour concentrations is given by

$$\chi_{(x,y)} = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma_y^2\,(x)}\right)}{\pi\,\sigma_y(x)\,\sigma_z(x)\,u} \sum_{j=-n}^{j=+n} \exp\left(\frac{-[h(x)+2jH]^2}{2\,\sigma_z^2(x)}\right) \qquad \text{(IV-1)}$$

where x=distance along plume axis (m)

y=perpendicular distance from the plume axis (m)

χ =pollutant concentration (g/m^3)

Q=emission rate (g/sec)

$\sigma_y(x)$, $\sigma_z(x)$ =horizontal and vertical dispersion coefficients for a particular atmospheric stability (A, B, C, D, E or F) and distance x

u=wind speed (m/sec)

$h(x)$ =effective emission height at distance x (m)

H=mixing height (m)

According to the Irwin scheme[3], the coefficients σ_y and σ_z also depend upon the amount of plume rise, the effective release height, mixing height and surface roughness. For the CRSTER Model, the lateral distance, y, is specified along an arc. This approximation saves computation time since dispersion coefficients only need to be computed for 5 ranges. For stability classes 5 and 6 only the j=0 term is included in the summation in Equation (IV-1). For distances greater than $2x_L$, where x_L is given by $\sigma_z(x_L)=1.6H$, Equation (IV-1) is approximated by

$$\chi_{(x,y)} = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma^2_y(x)}\right)}{\sqrt{2\pi}\,\sigma_y(x)\,u\,H} \qquad \text{(IV-2)}$$

The effective stack height h(x) will be greater than the actual stack height h_s due to the buoyancy of the plume. The expression for h(x) for stabilities A through D is given by[4,14]

$$h(x) = h_s + \Delta h$$

where

$$\Delta h = 1.6F^{1/3} u^{-1} x^{2/3} \text{ for } x \leq 3.5x^*$$

$$\Delta h = 1.6F^{1/3} u^{-1} (3.5x^*)^{2/3} \text{ for } x > 3.5x^* \text{ (Final plume rise)}$$

$$x^* = 14F^{5/8} \text{ when } F < 55 \text{ m}^4/\text{sec}^3$$

$$x^* = 34F^{2/5} \text{ when } F \geq 55 \text{ m}^4/\text{sec}^3$$

$$F = gwr^2 \left(\frac{T_s - T_a}{T_s} \right)$$

g = gravitational acceleration (m/sec^2)

w = stack gas exit velocity (m/sec)

T_s = stack gas temperature (K)

T_a = ambient temperature (K)

r = stack radius (m)

For stability classes E and F the plume rise is given by

$$\Delta h = 2.4 \left(\frac{F}{us} \right)^{1/3}$$

(Note: The constant "2.4" has since been changed to "2.6" in the recommended version of CRSTER.)

$$s = \frac{g}{T_\theta} \frac{d\theta}{dz}$$

θ = potential temperature (K)

z = distance above ground (m)

$\frac{d\theta}{dz}$ = 0.01 K/m for stability E

$\frac{d\theta}{dz}$ = 0.035 K/m for stability F

In the CRSTER Model, only the final plume rise is used in practice.

For receptor locations with elevations above the stack base, the plume height is reduced by an amount equal to the difference between these elevations. The mixing height, H, is assumed to have the same height above each receptor point, so that the mixing height follows the terrain. For calculated plume heights above the mixing height, zero concentration is assumed to occur at ground level.

For the calculation of hourly concentrations at the Clifty Creek and Tanners Creek networks, the CRSTER Model was used since the approximation of all stacks at the same physical location was appropriate. At the Muskingum and Gavin-Kyger-Sporn networks, this assumption could not be used. Instead, the multiple source model, MPTER, which was recently developed by the EPA Meteorology and Assessment Division, was used for the calculation of hourly SO_2 concentrations at the actual measurement sites. Strictly speaking, the MPTER code was used only in conjunction with the Pasquill-Gifford-Turner (P-G-T)[2] dispersion curves. A second multiple point source model, MULTP (Irwin), was developed by Teknekron Research especially for this study. This was done since there were portions of the MPTER code which were specific to P-G-T system. The only difference between both versions of CRSTER (Turner and Irwin) and the corresponding multiple source models [MPTER and MULTP (Irwin)] is that the distance from the plume centerline is measured along an arc in the first case and along a chord in the second. A sensitivity analysis has shown that the relative difference between calculated concentrations for these two methods is large only for receptors located so far from the plume centerline that the magnitude of the concentration itself is small with respect to the calculated peak centerline concentration. In light of this result, it was decided to simplify the nomenclature so that only two models, CRSTER (Turner) and CRSTER (Irwin) would be referred to in this model evaluation report. The terms in parenthesis refer to the method for calculation of dispersion coefficients. It should be remembered that in the application and evaluation of these two models for the Muskingum and Gavin-Kyger-Sporn networks, one is really talking about MPTER and MULTP (Irwin). The remainder of this section will describe the Turner and Irwin schemes for calculation of dispersion coefficients.

B. Turner Dispersion Coefficients

The variation of σ_y and σ_z with distance was first parameterized by Gifford[15] as shown in Figure IV-1(a) and (b). These curves represent a fit to a number of concentration field measurements, including those made during the Prairie Grass Study[16] conducted during the summer of 1956. Although these plume dispersion estimates were based largely upon ground level releases, they have also been applied to the dispersion calculation for elevated point source emissions. Since the measurements upon which these curves were based were taken within 1 km of the source, the shape of the σ_z curves beyond this distance is somewhat uncertain especially for the A and B stability classes. For the σ_z curves used in the CRSTER (Turner) Model, the variation of dispersion with distance for the A and B stabilities is represented by a simple power law[17] beyond 500 meters and 700 meters, respectively, as shown in Figure IV-2.

Within the CRSTER (Turner) Model, a stability dependent wind speed profile is used which does not vary with surface roughness. The power law exponents describing this wind speed profile were given in

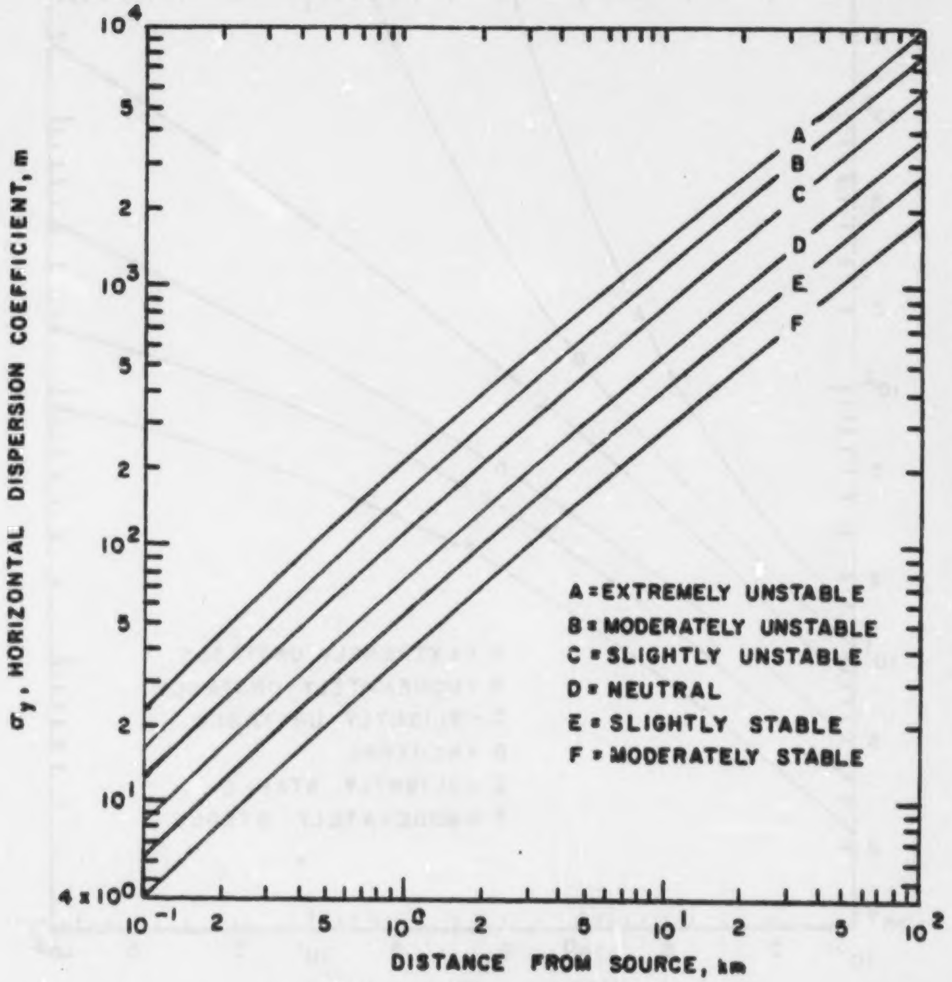


Figure IV-1(a). Horizontal Dispersion Coefficient as a Function of Distance According to Gifford[15]

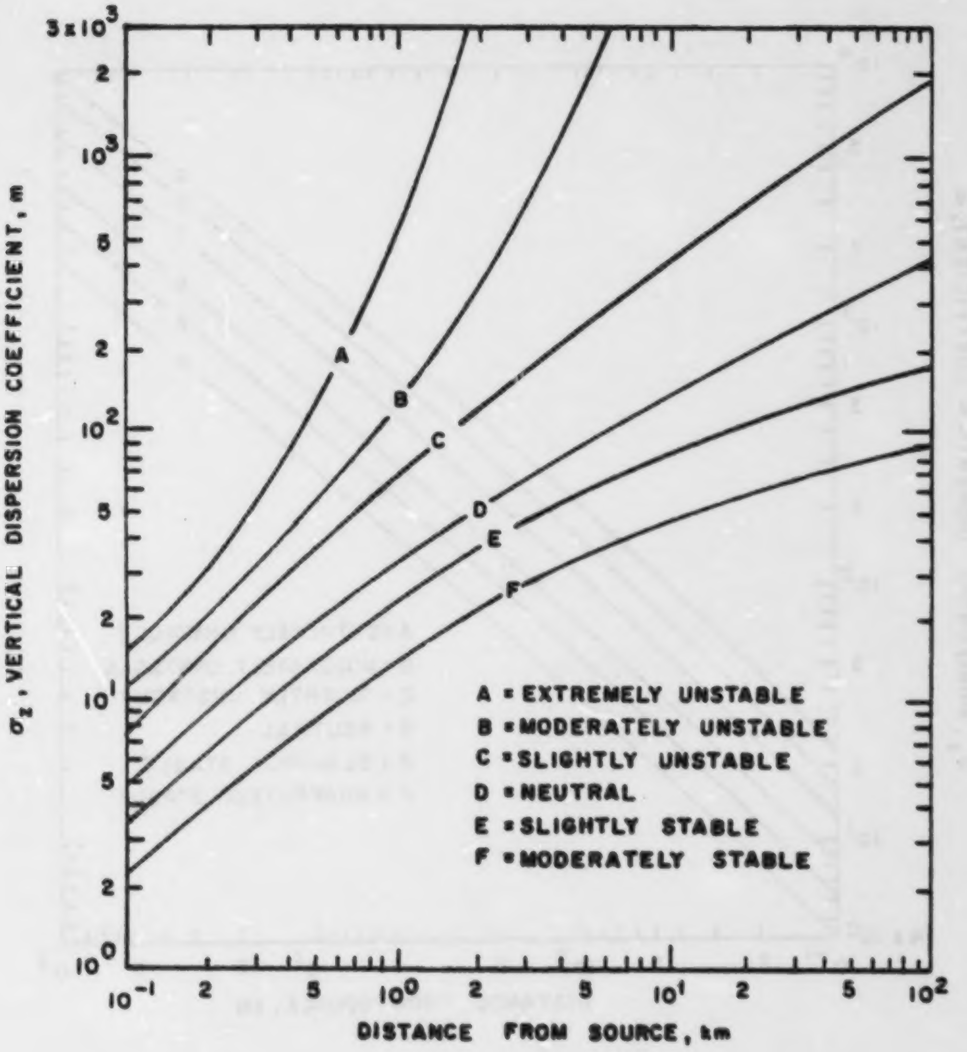


Figure IV-1(b). Vertical dispersion coefficient as a function of distance according to Gifford[15]

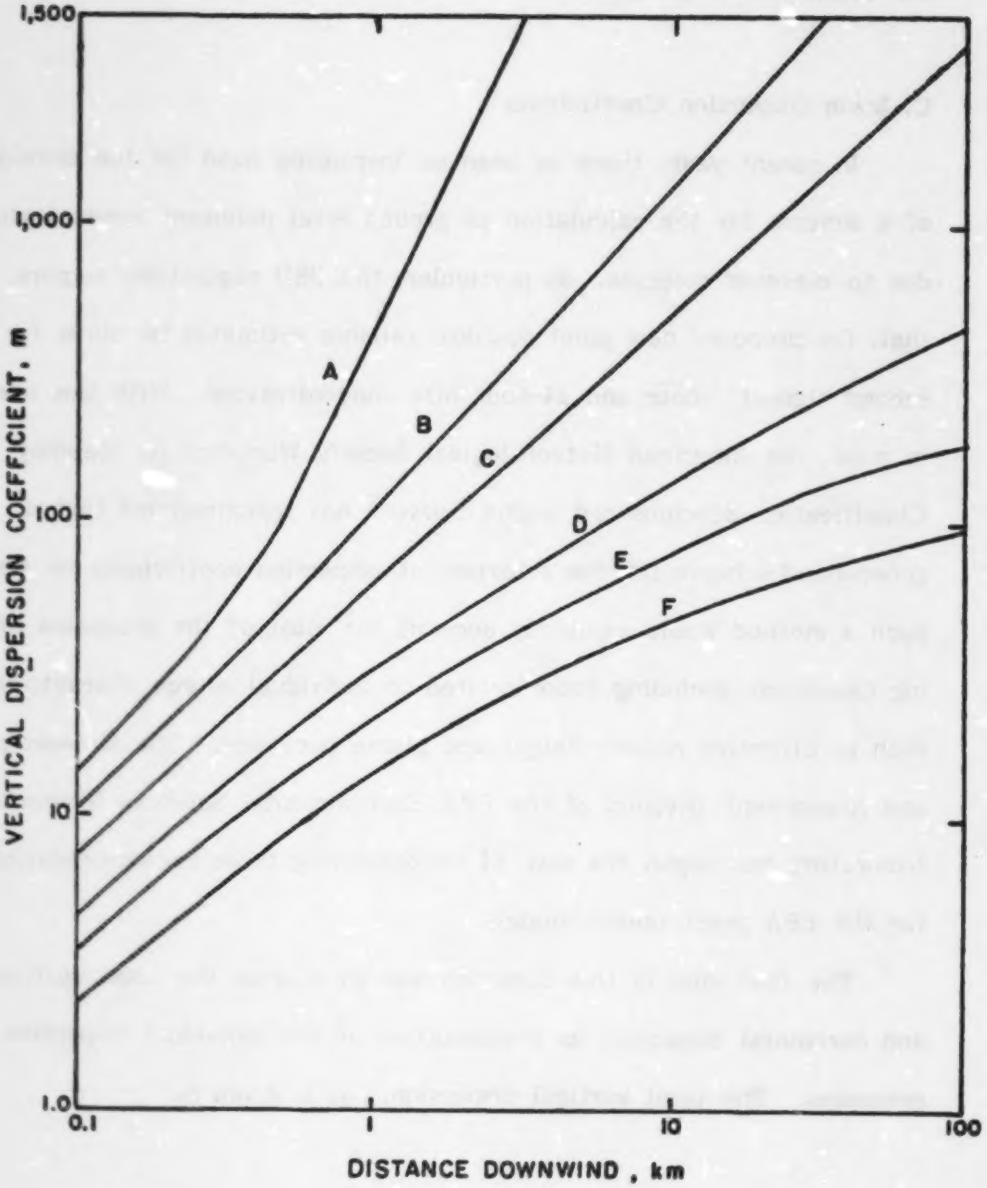


Figure IV-2. Vertical dispersion coefficient as a function of downwind distance from the source as currently employed in CRSTER (Turner)[17]

Table III-6. The wind speed, extrapolated from the 7 meter level to the top of the stack is used both for the plume rise calculation and in the denominator of Equation (1).

C. Irwin Dispersion Coefficients

In recent years there as been an increasing need for the development of a scheme for the calculation of ground level pollutant concentrations due to elevated releases. In particular, the PSD regulations require that, for proposed new point sources, reliable estimates be made for second highest 3-hour and 24-hour SO_2 concentrations. With this need in mind, the American Meteorological Society Workshop on Stability Classification Schemes and Sigma Curves[6] has recommended that a generalized scheme for the selection of dispersion coefficients be adopted. Such a method would explicitly account for most of the processes affecting dispersion, including those related to individual source characteristics such as effective release height and plume buoyancy. The Meteorology and Assessment Division of the EPA Environmental Sciences Research Laboratory has begun the task of implementing these recommendations for the EPA point source models.

The first step in this direction was to express the total vertical and horizontal dispersion as a summation of the individual dispersive processes. The total vertical dispersion, σ_z, is given by

$$\sigma^2_z = \sigma^2_{z_o} + \sigma^2_{z_i} \qquad \text{(IV-5)}$$

where σ_{z_o} = vertical dispersion due to atmospheric turbulence

σ_{z_i} = induced vertical dispersion due to buoyancy effects

In the generalized scheme, σ_z is treated as a function of surface roughness, effective release height, a surface stability parameter and the depth of the convectively mixed layer. The horizontal dispersion has three components:

$$\sigma^2_y = \sigma^2_{yo} + \sigma^2_{y_I} + \sigma^2_{y_{II}} \qquad \text{(IV-6)}$$

where σ_{yo} = horizontal dispersion due to atmospheric turbulence

σ_{y_I} = induced horizontal dispersion due to buoyancy effects

$\sigma_{y_{II}}$ = induced horizontal dispersion due to the turning with height of the horizontal wind direction

The first component, σ_{yo}, is considered to be a function of a surface stability parameter, depth of the convectively mixed layer and the lateral velocity fluctuation, which is in turn a function of averaging time and stability. It should be noted that this generalized scheme only strictly applies to flat terrain locations. For that matter, so does the P-G-T scheme. Nevertheless, the CRSTER (Irwin) Model does account for terrain by reducing the plume height by an amount equal to the difference between receptor and plant elevation.

The buoyancy related dispersion terms, σ_{z_I} and σ_{y_I}, are both approximated by the value $\Delta h/3.5$, where Δh is the calculated plume rise. The term $\sigma_{y_{II}}$ is given by the value $0.174x\Delta\theta$ where $\Delta\theta$ is the change in horizontal wind direction (in radians) over the vertical extent of the plume and x is the downwind distance in meters. The assumed wind direction shear as a function of stability class is presented in Table IV-1.

The vertical dispersion due to atmospheric turbulence is expressed as:

$$\sigma_{zo} = \sigma_w t F_z \qquad \text{(IV-7)}$$

Table IV-1.

Stability Dependent Wind Direction Shear Used in CRSTER(Irwin)

Stability Class	(°/1000m)
A	5
B	10
C	15
D	20
E	25
F	35

where σ_w = total standard deviation of the vertical wind component at the effective release height (m/sec)

t = travel time downwind (sec)

F_z = non-dimensional dispersion function which depends upon stability, effective release height and travel time downwind.

A similar expression ($\sigma_{yo} = \sigma_v t F_y$) is used for the horizontal dispersion due to atmospheric turbulence. On the basis of towing tank experiments, field studies and numerical simulations, value for F_z for unstable conditions is estimated as a function of mixing height (H), effective release height (h), stability parameter and transport time. In this generalized scheme, the stability parameter used is the Monin-Obukhov length scale, L, which is in turn a function of the friction velocity and the turbulence heat flux. Although L is seldom measured directly, it can be inferred from other measurements. Several methods[18,19] have been developed for estimating L from the Bulk Richardson number, $R_i = gZ\Delta T/(T_a U^2)$, where g is the acceleration due to gravity, T_a is the ambient air temperature (K) at height Z, U is the wind speed at height Z, and ΔT is the temperature difference between the height Z and a lower height Z_1. The upper measurement level must, however, be less than $|L|$, which means that the upper height is limited to about 10 meters, well below the upper level of 60 meters used on many network meteorological towers including those used in the AEP system. In this model evaluation study the only available classification of stability is the Turner scheme[5], which is based upon surface measurements at the nearest weather station. The relationship[20, 21] used in CRSTER (Irwin) between L, Turner stability class and surface roughness, Z_o, is given in Table IV-2. For values of $\frac{H}{L} > -10$, the estimate of F_z is based only upon the effective release

Table IV-2

Estimates of the Monin-Obukhov Length L(m) based upon Turner Stability Class and Surface Roughness Z_o(m)

Turner	a	b
A	-0.1136	-0.1029
B	-0.03849	-0.1714
C	-0.00807	-0.3049
D	0.0	- - -
E	0.00807	-0.3049
F	0.03849	-0.1714

where

$$\frac{1}{L} = aZ_o^b$$

height and depth of the planetary boundary layer.

For unstable conditions ($\frac{H}{L} < -10$), the value of F_y depends upon transport time, Monin-Obukhov length, mixing height and friction velocity. The friction velocity itself must be calculated from the Monin-Obukhov length and the surface roughness. For $\frac{H}{L} > -10$, F_y is only described as a function of transport time.

Even after values for F_y and F_z have been specified, the standard deviation of horizontal and vertical wind components σ_v and σ_w at a fixed point must also be estimated since they are not generally measured on site, and then rarely at plume height. In the CRSTER (Irwin) Model, these standard deviations are calculated from the mixing height, plume height, surface roughness and the Monin-Obukhov length, which is in turn estimated from the Turner Stability Class and surface roughness. This calculation of σ_v and σ_w, as a function of these variables, is based upon field and aircraft measurements. A more detailed description of the procedure for estimating F_y and F_z is given in Irwin's report.[3]

Finally, as stated in Part B, the power law wind profile coefficients used in CRSTER (Turner) depend only upon stability class. In the CRSTER (Irwin) Model the coefficients are, in addition, a function of surface roughness[3] as shown in Table IV-3.

Table IV-3

Power Law Wind Profile Exponents (α) Used in the CRSTER(Irwin) Model[a]

Stability Class	Surface Roughness (m)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
A	0.08	0.10	0.11	0.12	0.13	0.14	0.15	0.15	0.16	0.17
B	0.09	0.11	0.12	0.13	0.14	0.15	0.15	0.16	0.17	0.17
C	0.11	0.12	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.20
D	0.16	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27
E	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.31	0.32	0.33
F	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.48	0.49

[a] $U_h = U_{h_o}\left(\frac{h}{h_o}\right)^{\alpha}$

where

U_h = wind speed at height h

U_{h_o} = wind speed at reference height h_o

V. STATISTICAL EVALUATION OF MODEL PERFORMANCE

A. Introduction

This and the following two sections of the report evaluate the performance of the two point source models, using meteorological and monitoring data from power plant monitoring networks. This section summarizes the model predictions at all four sites and discusses the significant results of a detailed statistical analysis of model performance at the Clifty Creek station for 1975. Section VI discusses the evaluation of models in terms of the characteristics of the 25 highest annual measured and observed concentrations, while a case by case comparison of calculated and measured concentrations for the highest and second highest measured episodes at all 4 networks is given in Section VII. Appendix A deals with the general issue of model evaluation, discusses specific statistical performance measures and lists comprehensive statistical results for the study.

Model evaluation approaches are heavily dependent upon the ultimate objectives of the analysis. Three evaluation objectives have been identified in this project: quantifying model performance for comparison to other models or for evaluation with respect to regulatory use; comparing the model against a reference or baseline model to test "skill"; and analyzing model behavior for the purpose of understanding and improving the model. This section presents the highlights of the modeling analysis for each evaluation objective. Complete tables of results are presented in Appendix A.

B. Magnitude and Locations of Observed and Calculated 25 Highest/Year 3-Hour and 24-Hour SO_2 Concentrations

The time, magnitude and location of the 25 highest observed 3-hour and 24-hour SO_2 concentrations for 1975 and 1976 are given for each of the 4 networks in Tables B 1-4 of Appendix B. The "hour" column for the 3-hour episode listings refers to the last hour of the episode. After each episode listing there is a tally of the number of episodes by measurement site. Maps of the 4 networks are included at the end of Appendix B.

Beside each of the episode concentrations is the measured concentration, corrected for background. The background concentration used in this subsection and in Appendix B was taken to be the lowest reported episode average concentration for all of the network monitors. This method was used in Appendix B even though the on-site wind direction is not always a reliable indicator of the plume centerline location, especially under light wind conditions. Also, the previous hour's emissions can still impact a monitor even if the wind has turned. Any background subtraction technique, however, has problems if the network monitors are lined up along a particular direction from the plant. This non-symmetrical deployment of receptors was particularly troublesome at Muskingum. The resulting estimates of episode average background were, therefore, more uncertain. An analysis of different background subtraction techniques, as applied to the Clifty Creek plant, is presented in Appendix C.

The remaining tables in Appendix B give the SO_2 concentrations for the calculated 3-hour and 24-hour episodes. Each table describes 4 episodes for a particular network-model-year combination. For example, Table B-5(b) contains the episode data for CRSTER (Turner) for Clifty Creek 1976. The two reports at the top of the page give episode data for the full set of model receptors for 3-hour and 24-hour averaging times. Below each of these episode listings is a tally of episodes by model receptor range. In the case of the Muskingum network there was only one model receptor used for each distance range. The lower two episode listings in Table B-5(b) are for model calculations at the actual receptor locations for 3-hour and 24-hour averaging times. The model designation for these actual receptor locations is given below in the tally of episodes by receptor location. It should again be noted that only actual receptor locations ("selected receptors") were used in the model runs for Gavin-Kyger-Sporn.

Measured and calculated highest, second highest and 25th highest 3-hour and 24-hour episode concentrations are compared in Tables V-1(a) and (b) for the CRSTER (Turner) and CRSTER (Irwin) models respectively. This comparison is carried out for both the full and selected set of receptors, irrespective of the locations of the measured and calculated episodes. In the case of the Muskingum network the 25th highest measured value for both years has been omitted since no background value could be established. If, for the measured concentrations and the calculated concentrations for the actual receptors, one tabulates the absolute values of the differences between the corresponding highest, second highest and 25th highest values, then it is found that CRSTER (Turner) gives smaller differences than CRSTER (Irwin) as often as it gives larger differences. Both versions of CRSTER show about as many underpredictions as overpredictions for these cases. In this analysis the results for Tanners Creek were not used since both models

Table V-1(a). Comparison of Measured and CRSTER (Turner) Calculated SO_2 Concentrations

Network	Year	Measured Concen. ($\mu g/m^3$)a						Calc. Concen. ($\mu g/m^3$)-full						Calc. Concen. ($\mu g/m^3$)-selected					
		3-hour			24-hour			3-hour			24-hour			3-hour			24-hour		
		high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high
Clifty Creek	1975	1062	962	416	229	199	84	1629	1483	928	296	285	157	879	787	483	187	181	93
	1976	789	680	472	189	158	59	3307	2021	940	413	267	169	891	879	534	212	199	97
Tanners Creek	1975	1049	896	564	523	417	178	4668	4636	2555	913	861	488	2826	2679	892	598	568	152
	1976	1286	1257	359	495	360	116	4968	3562	2074	947	741	374	1940	1868	983	475	460	183
Muskingum	1975	698	639	361	304	151	-	1055	711	374	150	143	55	711	552	352	143	128	55
	1976	1300	1276	505	229	223	-	1258	1202	425	157	151	64	810	688	385	127	105	60
Gavin-Kyger-Sporn	1975	763	756	527	231	213	73	-	-	-	-	-	-	1155	633	406	158	157	78
	1976	1067	1057	588	346	242	86	-	-	-	-	-	-	696	621	433	202	180	90

[a] Measured concentrations corrected for background--see text

Note: Since this table represents comparisons of single values and not ensemble means the confidence one can put in these comparisons is necessarily limited.

Table V-1(b). Comparison of Measured and CRSTER (Irwin) Calculated SO_2 Concentrations

		Measured Concen. ($\mu g/m^3$)[a]						Calc. Concen. ($\mu g/m^3$)-full						Calc. Concen.($\mu g/m^3$)-selected					
		3-hour			24-hour			3-hour			24-hour			3-hour			24-hour		
Network	Year	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high	high	2nd high	25th high
Clifty Creek	1975	1062	962	416	229	199	84	1799	1786	1235	410	404	257	968	957	644	368	338	123
	1976	789	680	472	189	158	59	2039	1877	1282	470	432	269	1062	964	676	326	299	142
Tanners Creek	1975	1049	896	564	523	417	178	5451	5122	3178	1467	1152	656	3988	3686	1109	955	707	214
	1976	1286	1257	359	495	360	116	5705	4586	2524	1230	845	515	2813	2686	1310	585	559	236
Muskingum	1975	698	839	361	304	151	-	837	791	392	184	181	59	786	743	340	164	160	54
	1976	1300	1276	505	229	223	-	1208	1030	506	176	157	75	956	758	400	152	139	65
Gavin-Kyger-Sporn	1975	763	756	527	231	213	73	-	-	-	-	-	-	806	786	403	203	170	81
	1976	1067	1057	588	346	242	86	-	-	-	-	-	-	970	734	464	261	189	106

[a] Measured concentrations corrected for background--see text

Note: Since this table represents comparisons of single values and not ensemble means the confidence one can put in these comparisons is necessarily limited.

performed so poorly at this site.

The most frequent and second most frequent locations for the occurrence of measured and calculated 3-hour and 24-hour episodes at each of the 4 networks are given in Tables V-2(a) and (b) for the CRSTER (Turner) and CRSTER (Irwin) calculated episodes respectively. For this analysis, data for the years 1975 and 1976 have been combined. Only actual receptor locations are considered. The critical impact locations calculated by the CRSTER (Turner) and CRSTER (Irwin) models show better agreement with each other than they do with observed episode locations. Both models indicate that most of the 3-hour episodes at Clifty Creek should occur at North Madison (16 degrees, 4.5 km, 875 ft) while the most frequent observed 3-hour episodes occur at Bacon Ridge (40 degrees, 15 km, 910 ft). Neither model was able to account for the numerous 3-hour and 24-hour episodes at the Tanners Creek-Lawrenceburg site.

Table V-3 lists those cases for which there was a match between observed and calculated 24-hour episode dates. Since there is only an 8 percent probability that there will be 4 or more matching dates for two randomly selected samples of 25 dates, most of the cases reported in Table V-3 are significant. In most cases there is a matchup not only of the episode dates but also the locations of the episodes. In those cases where the locations do not match, the receptors are generally close to one another. The most notable exceptions are the two observed 24-hour episodes at the Tanners Creek Lawrenceburg site in 1976. The agreement between CRSTER (Turner) and observed 24-hour concentrations is relatively good considering the uncertainty of the background subtraction method and the concentration measurement technique. At Tanners Creek, Table V-2(a). Comparison of Measured Episode Locations and Those Calculated by the CRSTER (Turner) Model

	Measured Episode Location				Calculated Episode Location			
	3-hour		24-hour		3-hour		24-hour	
	most frequent	2nd most frequent	most frequent	2nd most frequent	most frequent	2nd most frequent	most frequent	2nd most frequent
Clifty Creek	Bacon Ridge	Rykers Ridge	Bacon Ridge	Hebron Church	North Madison	Rykers Ridge	Hebron Church	North Madison, Bacon Ridge
Tanners Creek	Lawrence-berg	Wilson Creek	Lawrence-berg	Dutch Hollow	Dutch Hollow	Wilson Creek	Dutch Hollow	Wilson Creek
Muskingum	Beverly	Rich Valley	Beverly	Rich Valley	Hackney	Beverly	Hackney	Beverly
Gavin-Kyger-Sporn	Lakin	Kerr	Kerr	Wolfpen, Mason	Wolfpen	Lakin	Wolfpen	Lakin

[a] "Tie" between two monitoring locations

Table V-2(b). Comparison of Measured Episode Locations and Those Calculated by the CRSTER (Irwin) Model

Network	Measured Episode Location				Calculated Episode Location			
	3-hour		24-hour		3-hour		24-hour	
	most frequent	2nd most frequent	most frequent	2nd most frequent	most frequent	2nd most frequent	most frequent	2nd most frequent
Clifty Creek	Bacon Ridge	Rykers Ridge	Bacon Ridge	Hebron Church	North Madison	Bacon Ridge, Rykers Ridge	North Madison	Rykers Ridge
Tanners Creek	Lawrenceberg	Wilson Creek	Lawrenceberg	Dutch Hollow	Dutch Hollow	Wilson Creek	Dutch Hollow	Wilson Creek
Muskingum	Beverly	Rich Valley	Beverly	Rich Valley	Hackney	Beverly	Hackney	Beverly, Rich Valley
Gavin-Kyger-Sporn	Lakin	Kerr	Kerr	Wolfpen, Mason	Wolfpen	New Haven	Wolfpen	Lakin

[a] "Tie" between two monitoring locations

Table V-3. Comparison of Measured and Calculated 24-hour Episodes Occurring on the Same Day

Network	Model	Year	Matching Day	Receptor for Obs. Conc.	24-hr Obs. Conc. (µg/m³)	Receptor for Cal. Conc.	24-hr Cal. Conc. (µg/m³)
Clifty Creek	Turner	1975	21 Oct	Bacon Ridge	199	Hebron Church	181
			11 Jan	Rykers Ridge	124	Bacon Ridge	164
			25 Feb	Rykers Ridge	173	Rykers Ridge	121
			16 Nov	Rykers Ridge	88	Bacon Ridge	115
			13 Dec	Hebron Church	138	Hebron Church	115
			5 Mar	Hebron Church	110	Hebron Church	100
			2 Nov	Bacon Ridge	148	North Madison	93
Clifty Creek	Turner	1976	25 Feb	Hebron Church	150	Hebron Church	159
			5 May	Hebron Church	128	Hebron Church	140
			17 Nov	Rykers Ridge	121	Bacon Ridge	119
			22 Apr	Rykers Ridge	141	Bacon Ridge	114
			24 Feb	Hebron Church	144	Hebron Church	110
Clifty Creek	Irwin	1975	25 Feb	Rykers Ridge	173	Rykers Ridge	159
			5 Mar	Hebron Church	110	N. Madison	168
			4 Jun	Hebron Church	103	N. Madison	129
			21 Oct	Bacon Ridge	199	N. Madison	368
			16 Nov	Rykers Ridge	88	Bacon Ridge	177
			13 Dec	Hebron Church	138	Hebron Church	175
Clifty Creek	Irwin	1976	14 Dec	Bacon Ridge	99	Hebron Church	243
			24 Feb	Hebron Church	144	North Madison	231
			25 Feb	Hebron Church	150	North Madison	235
Tanners Creek	Turner	1975	21 Feb	Wilson Creek	237	Wilson Creek	598
			9 Sep	Dutch Hollow	189	Dutch Hollow	532
			16 May	Dutch Hollow	211	Dutch Hollow	166
Tanners Creek	Turner	1976	24 Aug	Dutch Hollow	116	Dutch Hollow	460
			15 Mar	Dutch Hollow	142	Dutch Hollow	411
			16 Aug	Dutch Hollow	185	Dutch Hollow	393
			4 Oct	Wilson Creek	138	Wilson Creek	368
			24 Sep	Dutch Hollow	159	Dutch Hollow	219
			25 Nov	Lawrenceberg	495	Kilby Road	207
			15 Jun	Lawrenceberg	170	Kilby Road	207
			28 Sep	Dutch Hollow	153	Dutch Hollow	201
Tanners Creek	Irwin	1975	21 Feb	Wilson Creek	237	Wilson Creek	955
			9 Sep	Dutch Hollow	189	Dutch Hollow	557
			20 May	Lawrenceburg	184	Lawrenceburg	263

Table V-3. Continued

Network	Model	Year	Matching Day	Receptor for Obs. Conc.	24-hr Obs. Conc. (µg/m³)	Receptor for Cal. Conc.	24-hr Cal Conc. (µg/m³)
Tanners Creek	Irwin	1976	15 Mar	Dutch Hollow	142	Dutch Hollow	559
			4 Oct	Wilson Creek	138	Wilson Creek	585
			8 Oct	Dutch Hollow	131	Dutch Hollow	283
			24 Aug	Dutch Hollow	116	Dutch Hollow	532
			16 Aug	Dutch Hollow	185	Dutch Hollow	409
Muskin-gum	Turner	1975	29 Jan	Caldwell	151	Caldwell	77
Muskin-gum	Turner	1976	13 Sep	Rich Valley	172	Hackney	82
			6 May	Hackney	100	Rich Valley	81
			23 Apr	Beverly	170	Beverly	63
			25 Feb	Rich Valley	108	Hackney	60
Muskin-gum	Irwin	1975	29 Jan	Caldwell	151	Caldwell	81
Muskin-gum	Irwin	1976	13 Sep	Rich Valley	172	Hackney	95
			6 May	Hackney	100	Rich Valley	83
			25 Feb	Rich Valley	108	Hackney	81
			14 Jun	Hackney	121	Hackney	75
			5 May	Rich Valley	114	Hackney	70
Gavin-Kyger-Sporn	Turner	1975	19 Nov	Wolfpen	157	Lakin	144
			21 Oct	Mason	155	Wolfpen	128
G-K-S	Turner	1976	none				
G-K-S	Irwin	1975	21 Oct	Mason	155	Wolfpen	203
			8 Feb	Mason	148	Wolfpen	118
G-K-S	Irwin	1976	15 Feb	Mason	153	Lakin	138
			24 Feb	Mason	183	Wolfpen	116

both models considerably over predict 24-hour concentrations at the Dutch Hollow and Wilson Creek sites. Fewer 24-hour episode matches were found for the Muskingum and Gavin-Kyger-Sporn networks. This may in part be due to the use of off-site wind data for the model calculations. Both models had a tendency to underpredict 24-hour concentrations at Muskingum during these episodes. In several cases the episode was observed at Rich Valley and calculated to occur at Hackney. During the May 6, 1976 episode the observed peak was found at Hackney and the calculated peak was at Rich Valley. Few episode matches were found for the Gavin-Kyger-Sporn network. Those that did occur were at the Wolfpen, Mason, and Lakin monitors to the northeast of the Gavin and Kyger Creek power plants. In no case was there a match of actual locations.

C. Model Performance Evaluation Statistics

The remainder of this section describes the results of a detailed analysis of predicted and observed concentrations at the Clifty Creek network in 1975. All statistical tests consider only those results predicted by the two versions of CRSTER for the selected set of receptors. Therefore, we are evaluating the ability of the models to reproduce observed concentrations at six sites in the vicinity of Clifty Creek in 1975.

Air quality model performance can be evaluated in many different ways. It must be emphasized that no one set of evaluation statistics can be used to characterize the performance of every air quality model. Statistics that are appropriate for the evaluation of photochemical models or urban area source models may not be appropriate for point source model evaluation. Hayes[22] outlined a conceptual framework for the evaluation of models that included performance measures generally appropriate for the evaluation of models where single-source impacts were not critical. Javitz and Ruff[23] prepared an evaluation system for the RAM Model using the RAPS data base. Both approaches provide valuable insight for model evaluation but neither had to address in detail the peculiarities of single-source model evaluation.

Hayes[22] considered four generic performance measure categories: peak, station, area and exposure/dosage. The first category contains those measures derived from the differences between the predicted and observed peak concentrations as well as their location and timing. The second category includes measures based on concentration differences between predictions and observations at specific measurement stations. Within the third category are contained those measures based on concentration field differences throughout a specified area. The fourth category includes measures derived from differences in population exposure and dosage within a specified area. In this project, only the peak and station performance measures were used. The inability to completely specify the plume's location precluded consideration of area and exposure/dosage performance measures.

Station performance measures were presented by Hayes [22], Javitz and Ruff[23], and Bowne[24], as well as some informal EPA suggestions[25]. The form of most of these measures is similar. The two primary considerations are the absence of either systematic bias or gross error between the predictions and the observations. Note that this statistic is a comparison between concentrations predicted at the selected set of receptors only. No consideration for the full set of receptors is included in this analysis.

Before we discuss the individual performance measures it is appropriate to discuss background and its effects on statistical evaluation. The EPA model guideline[26] defines background concentrations to include pollutant concentrations due to natural sources and distant, unidentified sources. The importance of background concentrations increases for longer averaging times and for those areas where large sources are concentrated, such as the Ohio River Valley. Appendix C describes the background concentration procedure used in the project. Background concentrations must be considered in order to prepare an accurate estimate of predicted concentrations. Although background may not be a major factor for 1-hour and 3-hour peak estimates, it can be very important for 24 hour or annual averages. Thus it is appropriate to consider the background algorithm described in Appendix C as an additional module within both versions of the CRSTER Model.

The addition of background also introduces a complicating factor in the analysis because the inclusion of background significantly improves model performance. During periods when the station does not affect the receptor or monitor, background should be a good approximation to the observed concentration. For any individual monitor, the frequency of periods when the station impacts upon the monitor is relatively small but those cases are obviously important for model evaluation. The model has to predict station impacts well but does not really need to predict background as well. The error in any of the attributes associated with poor model prediction of station impacts could be reduced by eliminating all those periods when the difference is between background and observed only. This would reduce the effect of background.

Two ways to reduce the effect of background on the statistical indices are: 1) consider only those cases when either observed or predicted concentrations exceed a threshold concentration or 2) consider only those periods during which the source could have affected the monitor. If we consider only those cases when the concentrations exceed a threshold, then we should eliminate the effect of a large number of small background-observed residuals. Both procedures were included in this study and are discussed in later sections.

1. Systematic Bias

The systematic bias attribute assesses the tendency for a model to consistently underpredict or overpredict concentrations. Basically, the attribute is the mean residual between predicted and observed concentrations for a particular averaging time. Hayes[22] applies this statistic only to the values above a threshold (NAAQS is suggested) and normalizes by the average of the values above the threshold. EPA[25] suggested considering that all observed-predicted pairs be included and that the mean and standard deviation of the differences and the mean and standard deviation of the relative differences (normalized by the observed concentration) be calculated. For this project the differences (residuals) were defined as follows:

$$R = P + B - O \qquad \text{(V-1)}$$

where

R = Residual concentration ($\mu g/m^3$)

P = Predicted concentration ($\mu g/m^3$)

B = Background concentration ($\mu g/m^3$)

O = Observed concentration ($\mu g/m^3$)

Residuals were calculated for 1-hour, 3-hour and 24-hour periods at all six monitoring sites in the Clifty Creek network for one year (1975). The mean and standard deviation of all the residuals for a particular averaging time were calculated (Tables A-1 to A-6, Appendix A). The residual in equation V-1 was divided by the observed concentration to obtain the relative differences.

Table V-4 lists the attribute statistics for hourly concentrations in the Clifty Creek network and compares the CRSTER (Turner) and CRSTER (Irwin) results. Lines 1 and 5 list the average of all available hourly residuals at each site. A positive number indicates model overprediction. The magnitude of the number is important because the closer the residual is to zero the more accurate the model. Lines 3 and 7 normalize the raw residuals by dividing by the observed concentration. Note that this eliminates the units and changes the scale but does not alter the basic results significantly. The standard deviation lines (2, 4, 6 and 8) indicate the limits that can be placed around the averages. Smaller values are preferred to larger ones for this statistic.

In Table V-4 the only major difference between the 2 versions of CRSTER appears at the North Madison site where CRSTER (Turner) underpredicts and CRSTER (Irwin) overpredicts with a difference of 14 $\mu g/m^3$ between the two residuals. CRSTER (Irwin) overpredicts at four of the six sites, with residuals ranging from a 2 $\mu g/m^3$ underprediction to an 11$\mu g/m^3$ overprediction. CRSTER (Turner) underpredicts at four of the sites, with residuals ranging from a 5 $\mu g/m^3$ underprediction to a 5 $\mu g/m^3$ overprediction.

Figure V-1 shows the distribution of the monitoring sites by downwind distance and stack-monitoring site height difference. Note that 5 of the sites are within 30m of each other with only the Canip Creek

Table V-4

Systematic Bias Attribute Statistics for One Hour Prediction-Observation Pairs in the Clifty Creek Network (1975)

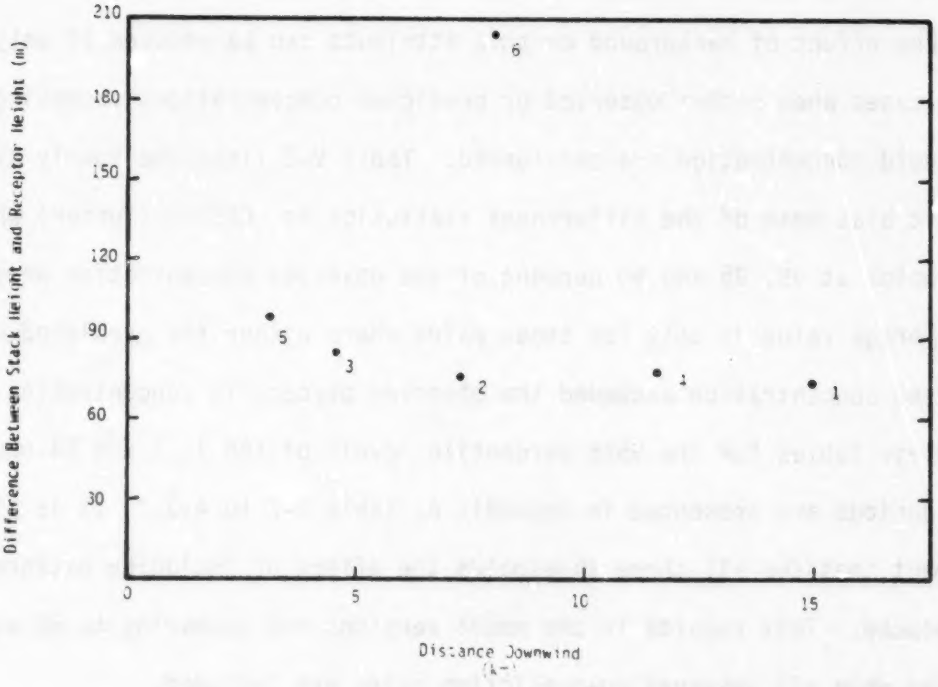
Line Number	Systematic Bias Attribute Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Camp Creek
	CRSTER (Turner) All Pairs with Background Included						
1	Mean of differences ($\mu g/m^3$)	-2.02	-1.35	-3.37	5.20	-4.78	1.31
2	Standard deviation of differences ($\mu g/m^3$)	78.0	71.0	82.9	79.0	37.5	55.1
3	Mean of relative differences	1.43	0.723	0.581	0.751	0.181	1.35
4	Standard deviation of relative differences	8.50	4.73	4.83	4.95	2.20	3.96
	CRSTER (Irwin) All Pairs with Background Included						
5	Mean of differences ($\mu g/m^3$)	-2.11	1.30	10.6	9.00	-1.92	2.63
6	Standard deviation of differences ($\mu g/m^3$)	77.8	73.6	111.0	88.0	53.8	53.2
7	Mean of relative differences	1.36	0.859	1.08	0.862	0.326	1.43
8	Standard deviation of relative differences	7.49	6.06	9.15	5.97	3.15	4.36

Note that the mean relative differences are more heavily affected by errors at low concentrations than are the mean differences. Thus, if there is an underprediction at low concentrations and a net overprediction at high concentrations, the mean differences statistic may show a net overprediction while the mean relative differences statistic shows an underprediction.

Figure V-1

Distribution of Clifty Creek Monitoring Sites by Distance Downwind and Difference Between Stack Height and Receptor Height. Key to Monitoring Sites:

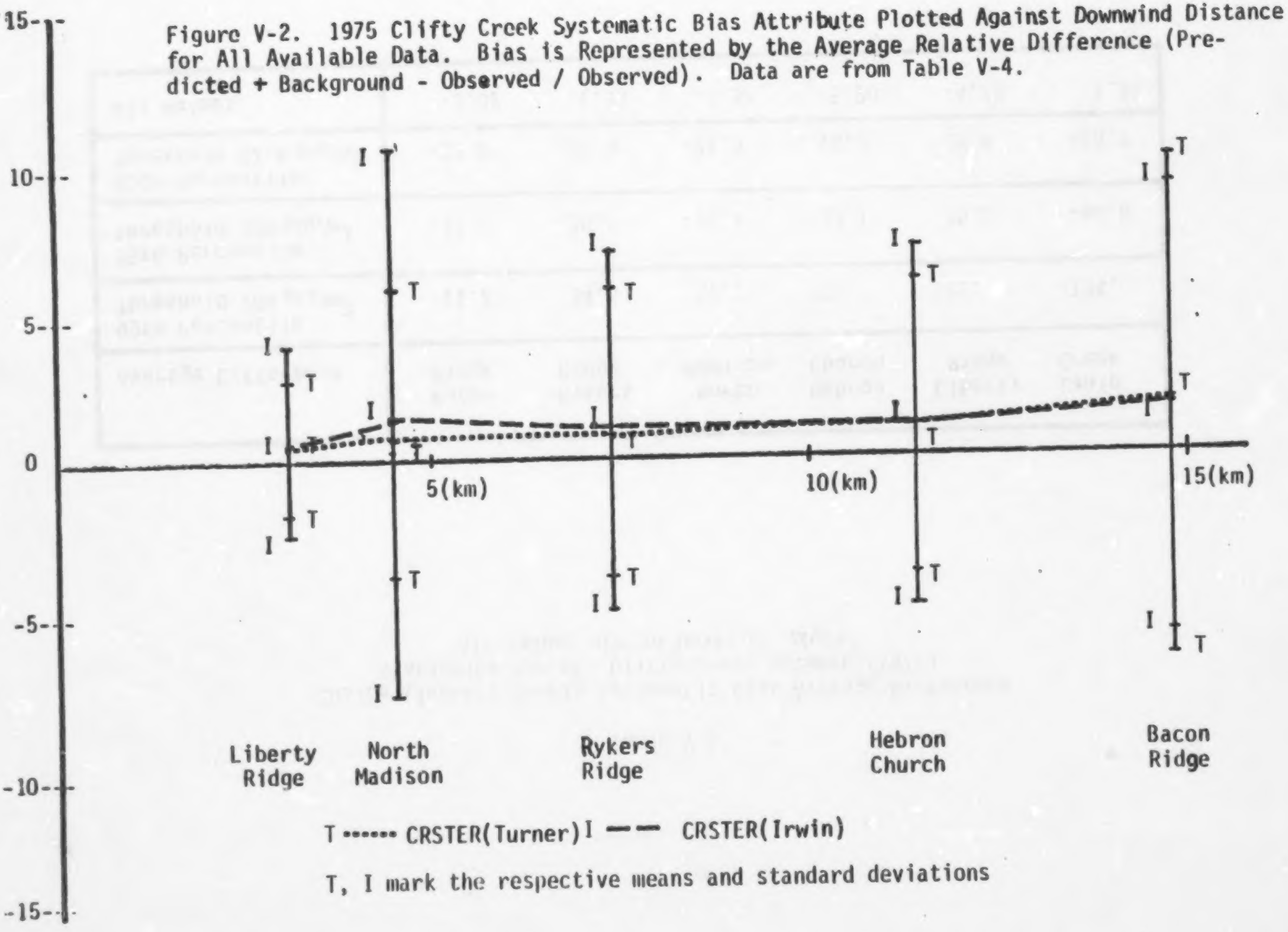
1. Bacon Ridge	4. Hebron Church
2. Rykers Ridge	5. Liberty Ridge
3. North Madison	6. Canip Creek



monitor showing a large height difference. The systematic bias attribute can be plotted against distance by using the results for the five monitoring sites if we assume that no other important factors such as terrain effects influence the results. For these five sites, Figure V-2 plots the average and the standard deviation of the residuals. There do not appear to be any significant differences between the two model versions with distance which would imply that there is no difference in the way the versions predict concentrations over the range of distances modeled here. Both model versions predict best (least bias) at Liberty Ridge and tend to predict worse (more bias) with distance from the plant.

The effect of background on this attribute can be reduced if only those cases when either observed or predicted concentrations exceeding a threshold concentration are considered. Table V-5 lists the hourly systematic bias mean of the differences statistics for CRSTER (Turner) when thresholds at 99, 95 and 90 percent of the observed concentration were used. The average value is only for those pairs where either the predicted or observed concentration exceeded the observed percentile concentration. (Complete tables for the 95th percentile levels of the 1, 3 and 24-hour time periods are presented in Appendix A, Table A-7 to A-9.) It is also apparent that for all three thresholds the effect of including background is reduced. This results in the model versions not appearing to do as well as when all observation-prediction pairs are included.

Figure V-2. 1975 Clifty Creek Systematic Bias Attribute Plotted Against Downwind Distance for All Available Data. Bias is Represented by the Average Relative Difference (Predicted + Background - Observed / Observed). Data are from Table V-4.



T, I mark the respective means and standard deviations

Table V-5

CRSTER (Turner) Hourly Systematic Bias Average Difference
Statistics for the Clifty Creek Network (1975)
All Values are in Units of $\mu g/m^3$

Average Difference	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
99th Percentile Threshold 284 $\mu g/m^3$	-11.2	34.5	89.2	131.	122.	-134.
95th Percentile Threshold 128 $\mu g/m^3$	-37.7	-28.5	-26.4	33.1	-39.0	-99.8
90th Percentile Threshold 82.6 $\mu g/m^3$	-33.8	-24.8	-27.9	18.3	-29.4	-58.2
All Values	-2.02	-1.35	-3.37	5.20	-4.78	1.31

Figure V-3 shows the 95th percentile percentage residuals for different source-receptor distances. Compared to the residuals on Figure V-2 that represent all hourly pairs, there is a wider variation of the means and more of a tendency to overpredict concentrations. CRSTER (Turner) appears to gradually overpredict by larger factors with distance downwind, while CRSTER (Irwin) overpredictions seem to peak within 5 km of the source and then gradually decrease. No statement as to the confidence in these trends can be made however.

2. Gross Error

The gross error attribute reflects the effect of both bias and scatter. This attribute is generally calculated by taking the average absolute value of the residuals between predicted and observed concentrations for a particular averaging time. Hayes[22] applies the statistic only to values above a threshold (NAAQS is suggested) and normalizes by the average of the values above the threshold. The average absolute error loss function suggested by Javitz and Ruff[23] is applied to all prediction-observation pairs but is equivalent otherwise to Hayes. EPA[25] also applied their gross error statistic to all prediction-observation pairs but suggest calculation of the mean and standard deviation of the absolute differences and absolute relative differences. For this project the gross error statistic was defined as follows:

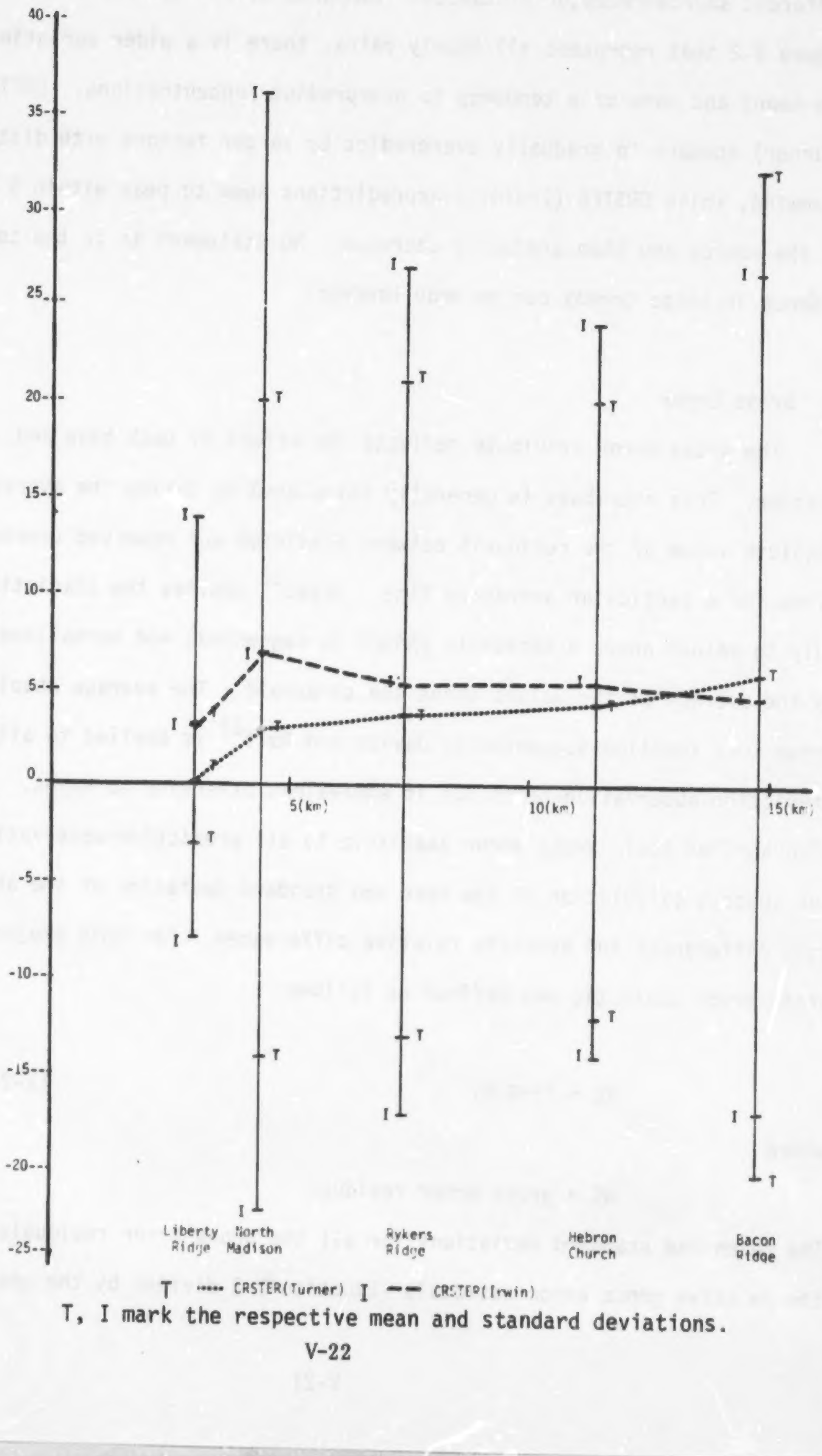
$$GE = |P+B-O| \qquad \text{(V-2)}$$

where

GE = gross error residual

The means and standard deviations for all the gross error residuals and the relative gross error residuals (Equation V-2 divided by the observed

Figure V-3. 1975 Clifty Creek Systematic Bias Attribute Plotted Against Downwind Distance for the Top Five Percent Data Only. Bias is Represented by the Average Relative Difference (Predicted + Background minus Observed/Observed)



T, I mark the respective mean and standard deviations.

value) were calculated for this project.

Table V-6 lists the summary of the gross error statistics of the hourly concentration. Low values of the gross error statistic indicate good agreement. The smallest gross error was noted at the Liberty Ridge monitor, with mean absolute differences of 12.3 $\mu g/m^3$ and 14.4$\mu g/m^3$ for CRSTER (Turner) and CRSTER (Irwin) respectively. The respective values for the mean of the relative absolute differences are 0.54 and 0.67. The largest mean absolute errors for at Bacon Ridge (30.7$\mu g/m^3$), for CRSTER (Turner) and at North Madison (34.1$\mu g/m^3$) for CRSTER (Irwin). The largest mean relative errors are at Bacon Ridge for both versions of the model. These are 1.87 and 1.74 for CRSTER (Turner) and CRSTER (Irwin), respectively.

Figures V-4 and V-5 show CRSTER (Turner) and CRSTER (Irwin) average absolute relative residuals for all hourly pairs and the 95th percentile pairs only, respectively. Similar trends as those noted for systematic bias residuals also show up here, namely CRSTER (Turner) gradually overpredicts by greater amounts and CRSTER (Irwin) overpredicts the peak and then gradually declines. Differences between CRSTER (Turner) and CRSTER (Irwin) are not that great, however. The same increase in mean absolute relative difference between the 95th percentile values only and all hourly values also occurs in the gross error residuals. Tables A7-A9 in Appendix A, list 95 percentile threshold residual statistics for all 3 averaging times.

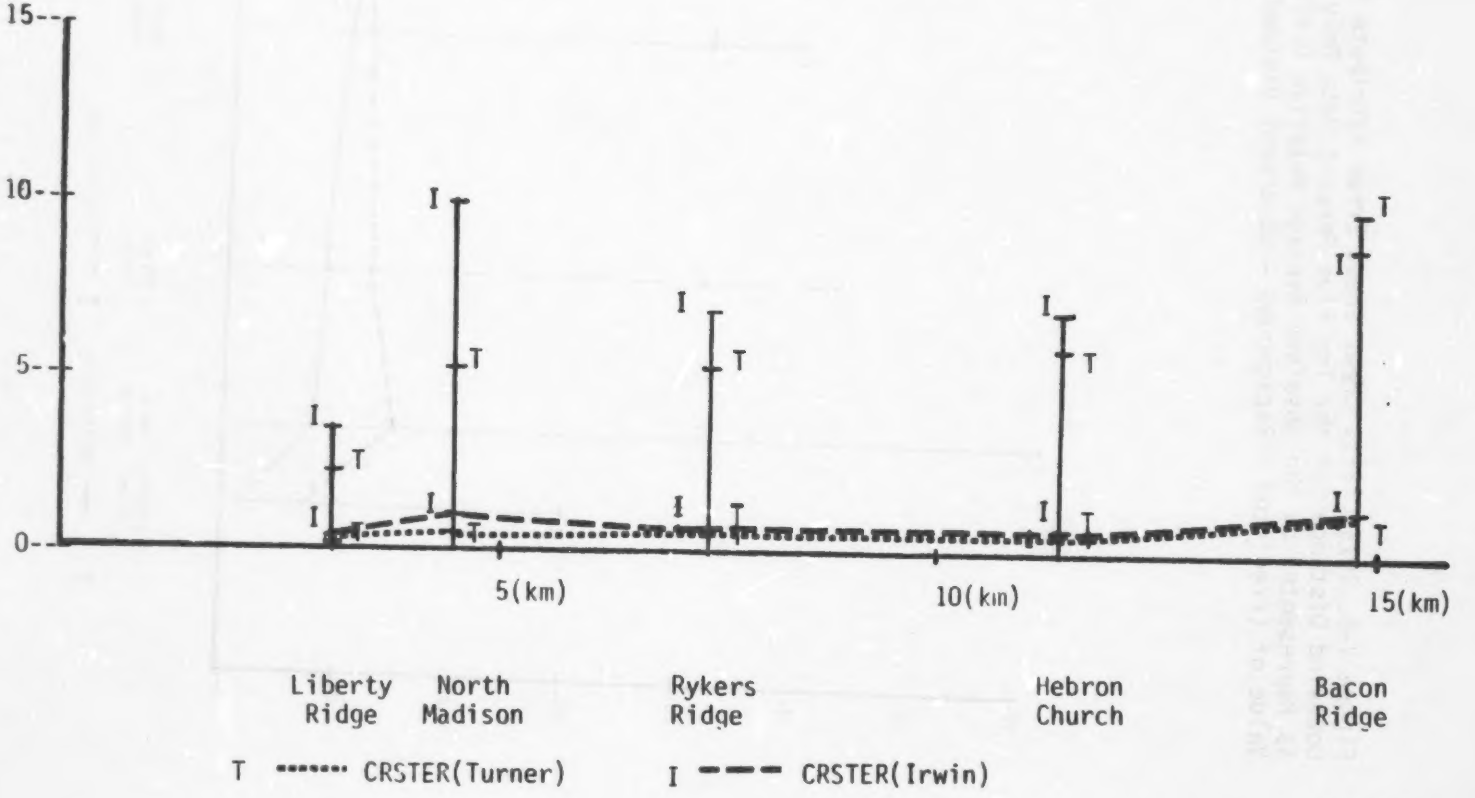
It is also useful to compare the results of both the systematic bias and the gross error attributes. Table V-7 lists hourly CRSTER (Turner) means for both attributes together. The systematic bias mean of the differences indicates that predictions are best (least bias) at Canip Creek closely followed by those at Rykers Ridge. However, the mean of the relative differences indicate that predictions at Liberty Ridge are best with Canip Creek fifth best and Rykers Ridge third

Table V-6

Gross Error Attribute Statistics for One Hour Prediction-Observation Pairs in the Clifty Creek Network (1975)

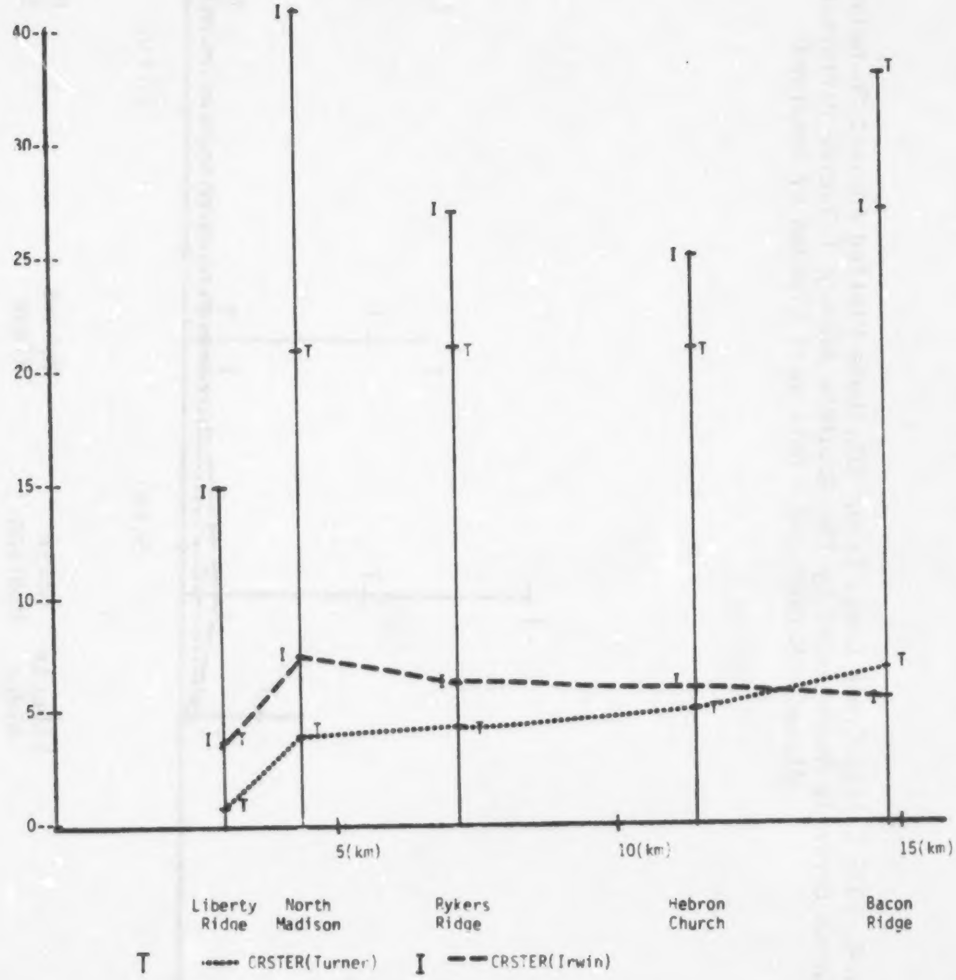
Line Number	Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Camp Creek
	CRSTER (Turner) All Pairs with Background Included						
1	Mean of absolute difference ($\mu g/m^3$)	30.7	21.1	24.6	27.7	12.3	19.7
2	Standard deviation of absolute differences ($\mu g/m^3$)	71.7	67.8	79.2	74.1	35.7	51.5
3	Mean of relative absolute difference	1.81	0.985	0.945	1.11	0.539	1.55
4	Standard deviation of relative absolute difference	8.42	4.68	4.78	4.88	2.14	3.89
	CRSTER (Irwin) All Pairs with Background Included						
5	Mean of absolute difference ($\mu g/m^3$)	30.3	22.8	34.1	30.1	14.4	19.4
6	Standard deviation of absolute difference ($\mu g/m^3$)	71.7	70.0	106.0	83.1	51.9	49.6
7	Mean of relative absolute difference	1.74	1.11	1.40	1.21	0.670	1.61
8	Standard deviation of relative absolute difference	7.41	6.02	9.10	5.91	3.10	4.29

Figure V-4. 1975 Clifty Creek Gross Error Attribute Plotted Against Downwind Distance for All Available Data. Gross Error is Represented by the Absolute Average Relative Difference (Absolute Value of (Predicted + Background - Observed) Divided by Observed).



T, I mark the respective means and standard deviations

Figure V-5. 1975 Clifty Creek Gross Error Attribute Plotted Against Downwind Distance for the Top Five Percent Data Only. Gross Error is Represented by the Absolute Average Relative Difference (Absolute Value of (Predicted + Background - Observed) Divided by Observed).



T, I Mark the respective means and standard deviations

Table V-7

Comparison of Gross Error and Systematic Bias Attributes for One Hour CRSTER (Turner) Prediction-Observation Pairs in the Clifty Creek Network (1975)

Line Number	Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
	Systematic Bias						
1	Mean of Differences ($\mu g/m^3$)	-2.02	-1.35	-3.37	5.20	-4.78	1.31
2	Mean of Relative Differences	1.43	0.723	0.581	0.751	0.181	1.35
	Gross Error						
3	Mean of Absolute Differences ($\mu g/m^3$)	30.7	21.1	24.6	27.7	12.3	19.7
4	Mean of Relative Absolute Differences	1.81	0.985	0.945	1.11	0.539	1.55

best. The gross error statistic indicates that Liberty Ridge predictions show the least scatter of the six stations. It appears that the mean of the differences was closer to zero at Canip Creek and Rykers Ridge than at Liberty Ridge because there was better cancellation of over and underpredictions at those two sites. According to the other statistics, predictions are much better at Liberty Ridge. It is also important to emphasize the use of all the systematic bias and gross error performance measures. If we had limited ourselves to the mean of the raw and absolute differences we may have drawn the erroneous conclusion that predictions at Canip Creek and Rykers Ridge were better than those at Liberty Ridge.

3. Peak Prediction

The peak prediction attribute estimates the models ability to correctly predict the peak concentration level, timing and location. Hayes[22] recommends a simple ratio calculation between the peak predicted concentration and the peak measured concentration. It is also recommended that the difference in the timing of the station peak should be included. Note, however, that calculation and prediction of peak location is very difficult for a plume model in the vicinity of a point source. Therefore we have not included those statistics and we recommend that they not be included for plume models unless extensive monitoring data are available.

The peak prediction attribute calculated for this model evaluation used statistics suggested by EPA staff[25]. Although essentially the same ratio suggested by Hayes[22], a more complicated procedure which involves sorting, geometric means and the range of ratios between the predicted and observed calculations was used. The top five observed concentrations and the predicted concentrations during those periods for each averaging time were assembled in Data Set A. (Note that only a single one-hour or three-hour average per day was chosen.) Data Set B consisted of the top 5 predicted concentrations and observed concentrations for each averaging period. The final data set (C) combined the top five observed and top five predicted concentrations. For each data set the geometric mean and the ratio of predicted to observed geometric means was calculated (Lines 1-3, Table V-8). The ratio for each of the top five paired concentrations and the largest and smallest of these ratios was determined (Lines 4-6, Table V-8). Ideally all the ratios should be close to one. However, the key ratios are those in data set C, because they are the most important with respect to regulatory applications. Current air quality regulations are concerned only with the peak observed and predicted concentrations regardless of the time that they occurred. In other words, the model predicted peak does not have to coincide with the observed peak. Data set C is concerned only with the top 5 predicted and observed concentrations and so is the most appropriate for regulatory analysis.

Table V-8 lists the ratios for the three-hour averaging time in 1975. Ratios less than one indicate model underprediction while those over one indicate model overprediction. In this table there do not appear to be significant differences between the two models. CRSTER (Turner) predicts smaller concentrations than CRSTER (Irwin) at all but one site. However, CRSTER (Turner) predicts better (ratios closer to 1) at the same number of sites as CRSTER (Irwin). The ratios (using data set C) ranged from 0.64 to 1.44. At this point it is impossible to determine why CRSTER (Turner) predicts smaller concentrations. It may be that the limited amount of data (1 year) did not

Table V-8

Model Peak Prediction Attribute
Ratio Between the Geometric Mean Predicted to Observed Concentration
for 3-Hour Averaging Periods in the Clifty Creek Network (1975)

Data Set	Description
Data Set A:	Five highest observed concentrations and the predicted + background concentrations during those peak observations
Data Set B:	Five highest predicted + background concentrations and the observed concentrations during those peak predictions
Data Set C:	Five highest observed and predicted + background concentrations during the year regardless of when they occurred

Line Number	Model Version	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
	CRSTER (Turner)						
1	Data Set A	0.150	0.499	0.299	0.361	0.617	0.239
2	Data Set B	5.66	7.13	5.29	2.49	5.78	2.27
3	Data Set C	0.934	1.34	1.04	1.25	1.26	0.638
	CRSTER (Irwin)						
4	Data Set A	0.155	0.375	0.498	0.406	0.671	0.376
5	Data Set B	1.67	4.04	4.37	4.07	4.93	3.39
6	Data Set C	1.05	1.18	1.37	1.44	1.80	0.678

include the entire range of expected conditions and that, in general, CRSTER (Irwin) predicts smaller concentrations than CRSTER (Turner). This hypothesis could be tested by including more data in the sample.

Figure V-6 compares the highest and second-highest concentrations at the six sites, as might be used in regulatory applications. CRSTER (Irwin) and CRSTER (Turner) appear to do about equally well. Neither appears to be consistently higher or lower than the observed.

4. Accuracy Scores

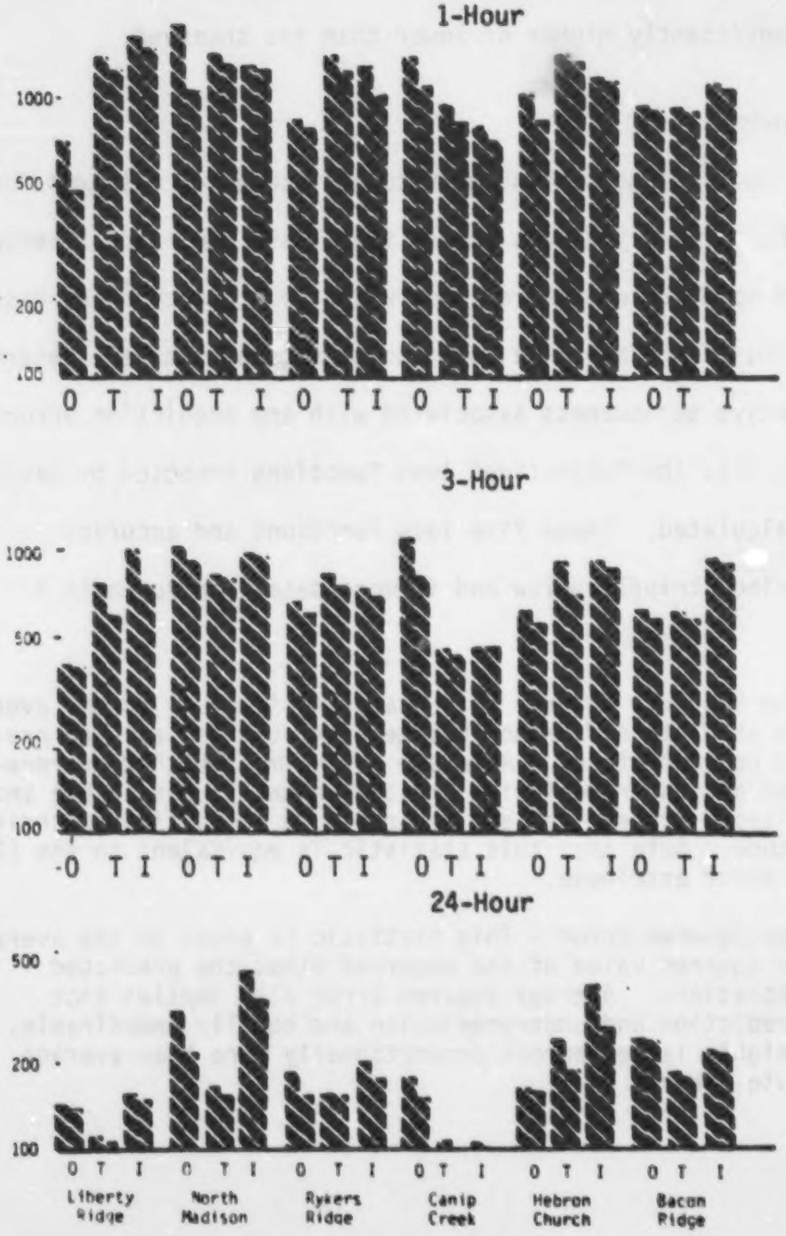
Javitz and Ruff[23] suggested using accuracy scores as measures for model evaluation. Accuracy scores assess the "loss" due to differences in predicted and observed concentrations, with the accuracy score based on a different loss function. The loss function quantitatively determines the loss or relative seriousness associated with any prediction errors. For this project only the "objective" loss functions proposed by Javitz and Ruff were calculated. These five loss functions and accuracy scores are described briefly below and in more detail in Appendix A.

1) Average Absolute Error - This statistic is equal to the average of the absolute difference between the observed and the predicted concentrations. Absolute error implies that overprediction and underprediction are both equally undesirable and that larger errors are less desirable in proportion to their magnitude. Note that this statistic is equivalent to the EPA gross error attribute.

2) Average Squared Error - This statistic is equal to the average of the squared value of the observed minus the predicted concentrations. Average squared error also implies that overprediction and underprediction are equally undesirable, but weights larger errors proportionally more than average absolute error.

Figure V-6. Highest and Second Highest Observed and Predicted 1-Hour, 3-Hour, and 24-Hour Concentrations. Log Scale Used for Concentrations.

O = Observed T = CRSTER (Turner) I = CRSTER (Irwin)



3) Percent Incorrect Predictions with Absolute Error Threshold - This loss function counts only prediction errors that exceed a certain absolute threshold against the model, so that the model is considered incorrect only when the threshold was exceeded. Both underpredictions and overpredictions are judged to be equally undesirable but the magnitude of the error is ignored.

4) Percent Incorrect Prediction with Constant Percentage Error Threshold - This accuracy score is similar to 3 except that a percentage rather than an absolute threshold is used.

5) Symmetric High-Low Loss Function - This accuracy score is the percentage of false exceedances of the threshold and failures to predict actual pollutant alert levels. The magnitude of the prediction errors are not considered.

These accuracy scores and their associated confidence limits were calculated for the 1-hour, 3-hour, and 24-hour averaging times. Table V-9 summarizes the scores, for hourly values of CRSTER (Turner) with complete tables given in Appendix A (Tables A10-A12). The lower the accuracy score, the better the agreement between observations and predictions. Smaller confidence intervals indicate that we can have more confidence in the results. Average absolute error is equivalent to the gross error attribute. Average squared error weights large mispredictions more than small mispredictions. Note that Liberty Ridge results are best for both tests. Bacon Ridge is the worst according to the average absolute error but two stations are worse for the average squared error. Therefore, there must be more large errors at those two stations than at Bacon Ridge. The third and fourth statistics consider a concentration difference between observed and predicted wrong only if it exceeds the threshold. For this analysis, an arbitrary threshold of 5μg/m^3 was used for the constant absolute error threshold and a 5% threshold was used for the constant percentage error threshold. About half the values are in error by 5μg/m^3 or more, and a few percent of the values are in error by 5% or more. Again, Liberty Ridge predictions agree best with observations for both statistics. The final

Table V-9

Accuracy Scores and Confidence Limits for the Clifty Creek Network (1975) CRSTER (Turner) Hourly Concentration Predictions With Observed Concentrations

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	30.7	21.1	24.6	27.7	12.3	19.7
Confidence Limits	1.32	1.75	0.753	1.18	0.676	0.302
Average Squared Error						
Statistic ($\mu g/m^3$)	6080	5040	6880	6270	1430	3030
Confidence Limits	708	1020	947	944	700	384
Fraction Incorrect Predictions with Absolute Error Thresholds $\varepsilon = 5\ \mu g/m^3$						
Statistics	0.685	0.508	0.578	0.623	0.483	0.621
Confidence Limits	0.0045	0.0044	0.012	0.011	0.0043	0.0042
Fraction Incorrect Predictions with Constant Percentage Error Threshold $\varepsilon = 5\%$						
Statistics	0.0609	0.0269	0.0233	0.0338	0.0161	0.0632
Confidence Limits	0.0030	0.0016	0.0013	0.0037	0.0029	0.0030
Symmetric High-Low Loss Function Cutoff = 250 $\mu g/m^3$						
Statistic	0.0387	0.0243	0.0232	0.0332	0.0058	0.0130
Confidence Limits	0.0037	0.0030	0.0011	0.0021	0.0011	0.0015

accuracy score was calculated so that predictions and observations were considered correct if both exceeded or were less than 250 $\mu g/m^3$. This statistic shows that it is difficult to predict peaks at Hebron Church and Bacon Ridge.

D. Model Skill

Determining model skill is similar to evaluating model performance with the statistics described above. Model skill is a relative performance measure that compares the predictions of a test model against a baseline reference model for which there is no implied skill. This is a concept borrowed from weather forecasting where forecasts based on simple concepts like persistence or climatology are used as reference models. To date, model evaluation has concentrated more on the development of scores or tests and less on comparison of those tests against a reference model.

Model evaluation should include a skill comparison of the performance measures calculated for the test model and those calculated for a reference model with no implied skill. A peformance measure may be meaningless without such a comparison because the same values of the statistic might have been obtained by a prediction method that requires no knowledge of pollutant dispersion. Dispersion models are becoming increasingly complex and expensive, so some measure of their skill compared to simpler approaches would be a desirable goal.

Two reference models were used in this analysis. The first reference model was determined by chance but was appplied only to a few statistical procedures, e.g. contingency tables. Background concentrations estimated by the EPA[26] method (Appendix C) were used as the second reference model. Background concentrations were used as the predictions and compared to the observations; then the performance measures described in the previous section were applied. If the two versions of CRSTER were more accurate than background as an estimator of observed concentrations then skill would be shown.

Other reference models could be used for future work. For example, Clark and Karl[27] used persistence as a reference model. Their model predicted daily ozone levels and they compared it to the previous day's ozone level. A second alternative would be to develop a climatology of short-term concentrations. For example, the stability-wind speed frequency distribution for each source-receptor pair could be determined, and then the concentration for each hour the wind is in the sector could be calculated using the appropriate stability and wind speed. Wind direction within the sector could be simulated by using normalized random numbers, if the mean wind direction is set equal to the source-receptor centerline and varies by the standard deviation of wind direction appropriate to each stability class determined using, for example, the Brookhaven classification scheme.

A contingency table is a convenient way to display a joint frequency distribution, and can be used to develop a simple skill score. For this analysis, the contingency tables show the relationship between observed and predicted concentration. The approximate quartiles of the observed concentrations were used to specify four categories. In general, statistics to analyze contingency tables require a minimum number of observations within each bin in the table, so a small number of categories was deliberately chosen to meet this requirement. The contingency table has most of the observations in the frequency distribution on the major diagonal when the predictions and observations are well correlated. Panofsky and Brier[28] describe a number of easily obtained scores that can be derived from a contingency table. For example, the percentage correct can be obtained by summing the number of observation prediction pairs in the major diagonal and dividing by the total number of pairs. Most computer statistical packages offer a number of statistics for contingency table analysis. Appendix A summarizes a number of these.

A skill score(s) can also be derived from the information contained in a contingency table . The skill score is defined as:

$$S = \frac{P-R}{T-R} \qquad \text{(V-3)}$$

where P is the number of correct forecasts, T is the total number of forecasts, and R is the number of correct predicted by a reference model. The score is equal to 1 when all forecasts are correct and is equal to zero when no correct forecasts are made. The expected number of correct predictions using background and chance as the baseline models were used to calculate 2 CRSTER Turner and Irwin skill scores for each averaging time.

Three other statistics measuring association were evaluated for each contingency table: the Pearson correlation coefficient, the Gamma statistic and the percent correct. The Pearson correlation coefficient (r) measures the degree of association between observed and prdicted concentrations such that a value +1 indicates perfect correlation and -1 indicates a perfect inverse correlation with zero representing no relationship.

The Gamma statistic is a nonparametric measure of association that is based on the relative ordering of pairs of cases (e.g. hours)[29]. The Gamma statistic is defined as follows:

$$\text{Gamma} = \frac{C-Q}{C+Q} \qquad \text{(V-4)}$$

where C is the number of concordant pairs and Q is the number of discordant pairs, considering every possible pair of hours in the table. Like most other association measures, Gamma ranges from +1 to -1; a zero value of Gamma indicates no association, i.e. an equal or random pattern of agreement or disagreement. (See Appendix A).

The third association statistic, the percentage correct, is simple and provides a check on both Gamma and r. If the percentage correct is fairly large and both Gamma and r are close to +1, the model is probably doing well. Again, the most benefit of these statistics is in the relative comparison of their values for a baseline model compared to the values for the test model.

Table V-10 includes three contingency tables that represent hourly observations and predictions at the Bacon Ridge Monitor in 1975. Complete contingency table summaries are presented in Appendix A—Tables A-13 through A-15. The first table considers the CRSTER (Turner) predicted with background included and observed concentrations, the second table considers the hourly background concentrations and the observed concentrations, and the third represents a model with no skill predicting concentrations against observed values. The values in the chance table are calculated by multiplying the row total and column total and dividing by the table total from Table V-10(a). Table V-11 summarizes the contingency tables and includes statistics for the analagous

Table V-10

Bacon Ridge One Hour Contingency Tables for 1975 - Numbers Represent Frequency of Hours Where Observed and CRSTER (Turner) Concentrations Occurred in the Same Bin. Numbers in Parentheses are the % Occurrence of the Same.

Table V-10a. Predicted vs Observed Concentrations ($\mu g/m^3$)

Predicted Concentration

		0-15	15.1-30	30.1-50	>50.1	Total
Observed Concentrations	0-15	2261(28.7)	653(8.3)	156(2.0)	167(2.1)	3237(41.0)
	15.1-30	701(8.9)	874(11.1)	291(3.7)	191(2.4)	2057(26.1)
	30.1-50	80(1.0)	374(4.7)	334(4.2)	233(3.0)	1021(12.9)
	>50.1	72(0.9)	194(2.5)	373(4.7)	934(11.8)	1573(19.9)
	Total	3114(39.5)	2095(26.6)	1154(14.6)	1525(19.3)	7888(100)

Table V-10b. Background Reference vs Observed Concentrations ($\mu g/m^3$)

Background Concentrations

		0-15	15.1-30	30.1-50	>50.1	Total
Observed Concentrations	0-15	2400(29.8)	694(8.6)	143(4.8)	110(1.4)	3347(41.6)
	15.1-30	735(9.1)	898(11.2)	303(3.8)	136(1.7)	2072(25.8)
	30.1-50	89(1.1)	399(5.0)	335(4.2)	204(2.5)	1027(12.8)
	>50.1	104(1.3)	232(2.9)	411(5.1)	847(10.5)	1594(19.8)
	Total	3320(41.4)	2223(27.6)	1192(14.8)	1297(16.1)	8040(100)

Table V-10c. Chance or No-Relation Table ($\mu g/m^3$)

Chance Predicted Concentration

		0-15	15.1-30	30.1-50	>50.1	Total
Chance Observed Concentrations	0-15	1278(16.2)	860(10.9)	474(6.0)	626(7.9)	3237(41.0)
	15.1-30	812(10.3)	546(6.9)	301(3.8)	398(5.0)	2057(26.1)
	30.1-50	403(5.1)	271(3.4)	149(1.9)	197(2.5)	1021(12.9)
	>50.1	621(7.9)	418(5.3)	230(2.9)	304(3.9)	1573(19.9)
	Total	3114(39.5)	2095(26.6)	1154(14.6)	1525(19.3)	7888(100)

Table V-11

Summary of Bacon Ridge Contingency Table Results

	Bacon Ridge	
	CRSTER(Turner)	CRSTER(Irwin)
Percent Correct (model)	55.8	56.0
Percent Correct (background)	55.7	55.7
Percent Correct (chance)	28.9	28.9
Skill Score (background)	0.0023	0.0068
Skill Score (chance)	0.379	0.381
Correlation Coefficient (model)	0.649	0.651
Correlation Coefficient (background)	0.654	0.654
Percent Correct (model) upper quartile only	30.1	30.3
Percent Correct (background) upper quartile only	29.3	29.3
Percent Correct (chance) upper quartile only	3.9	3.9
Upper Quartile Skill Score (background)	0.0113	0.0141
Upper Quartile Skill Score (chance)	0.273	0.275

CRSTER (Irwin) tables. Both versions of CRSTER predict over 55 percent of the concentrations in the correct category. However, note that both versions only slightly improve the percent correct predicted using just background, and that they both are much better than the random model.

When only the upper quartile is considered, the two versions do improve their performance compared to the background reference model. Note that the skill scores improve by an order of magnitude and that the skill scores for the random model decrease slightly. Correlation coefficients for the two versions of CRSTER are slightly lower than those for background. This implies that there is a little less scatter in the observed vs background tables.

The skill score is a simple measure of skill that is best used for comparing contingency tables. It would be useful to have an analogous statistic that could be applied to other performance measures. The analagous statistic should behave similar to the skill score, i.e. positive values imply "better" predictions than the reference model predictions, zero implies no difference between the test model and reference model, and negative implies that the model predicts "worse" than the reference model. One possible candidate for the performance measure skill score is the percentage difference between the absolute value of a performance measure for observed and model predicted concentrations and the same performance measure for observed and reference model predicted concentrations. For the performance measures and accuracy scores described in Section C the following equation can be used:

$$S = \frac{|(I-R)| - |(I-P)|}{|P|} \qquad \text{(V-5)}$$

where R = value of performance measure calculated for reference model and observations

P = value of performance measure calculated for test model and observations

I = index limit of perfect performance measure

This equation includes I because one of the performance measures (model peak prediction) is based on a value of one. All the others described use zero as the ideal value and the equation can be reduced accordingly.

The performance measure skill score requires reference model performance measures to be calculated for each skill score desired. Background concentrations were used to illustrate the use of these skill scores for the model peak prediction, systematic bias, and gross error performance measures (Table V-12). The model peak prediction and systematic bias performance generally demonstrate skill (except for bias at Canip Creek) because the performance measure skill scores are all positive. Note however, that the Gross Error attribute is always showing no skill. This example illustrates one problem with background as a reference model. The gross error performance measure skill score is negative because using background as a prediction model does not allow large over-predictions but the diffusion models do. Thus the absolute value of the residuals is larger for the models than the residuals and we have a reason to allow the model to demonstrate no skill for that attribute.

The skill score can also be used to illustrate differences between the two versions of CRSTER. Table V-12 also lists the differences

Table V-12. Performance Measure Skill Scores for Hourly Concentration Estimates in the Clifty Creek Network (1975)

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
CRSTER(Turner)						
Model Peak Prediction (Data Set C)	26.0	4.28	12.8	3.95	0.979	22.4
Systematic Bias	4.89	5.25	2.35	0.737	0.291	-0.115
Gross Error	-0.176	-0.171	-0.195	-0.213	-0.0732	-0.-558
CRSTER(Irwin)						
Model Peak Prediction (Data Set C)	8.23	3.12	16.6	5.26	0.725	4.14
Systematic Bias	4.64	5.49	0.0660	0.00333	2.21	-0.559
Gross Error	-0.165	-0.232	-0.419	-0.276	-0.208	-0.0412
Difference CRSTER (Turner) minus CRSTER(Irwin)						
Model Peak Prediction	17.8	1.16	-3.8	-1.3	0.254	18.3
Systematic Bias	0.25	-0.24	2.28	0.734	-1.92	---
Gross Error	---	---	---	---	---	---

between the CRSTER (Turner) scores and the CRSTER (Irwin) scores for those statistics that show skill. Positive numbers indicate CRSTER (Turner) predicts better than CRSTER (Irwin). Note that this exercise indicates that CRSTER (Turner) predicts hourly concentrations better than CRSTER (Irwin). This also leads us to the next section wherein the differences between the models and the results predicted by the models will be discussed further.

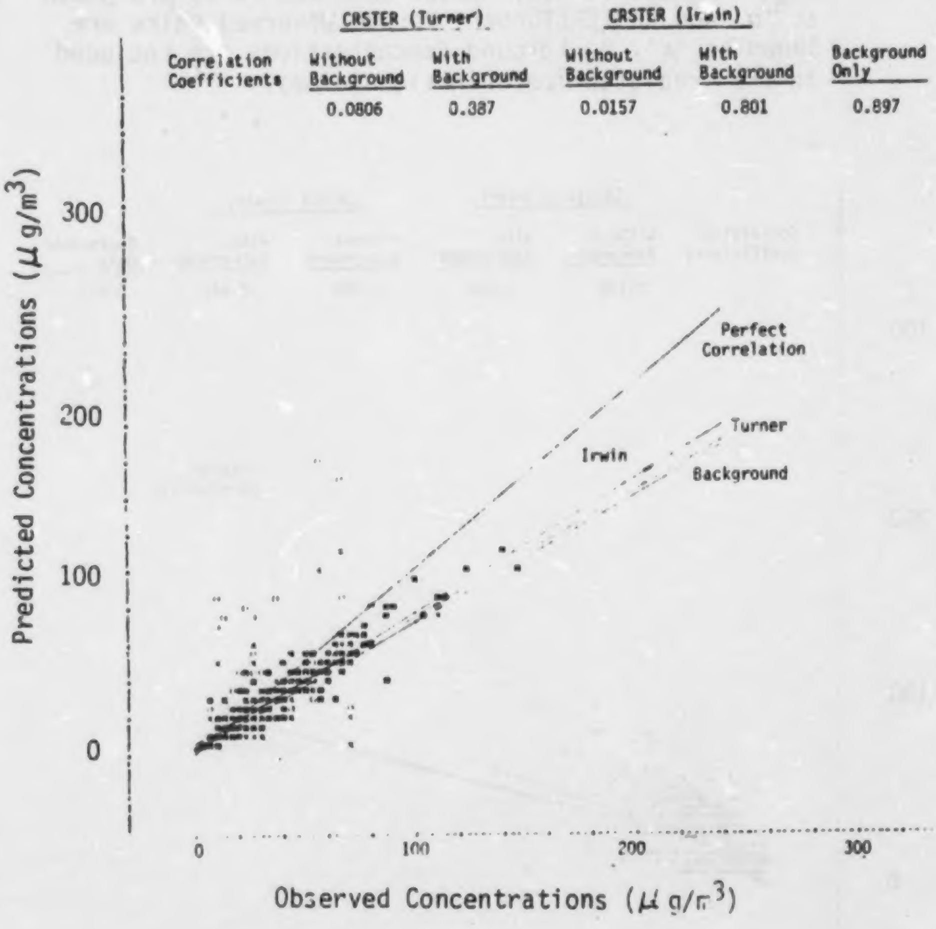
E. Model Algorithm Evaluation

Statistical tests can also be used to analyze model behavior for the purpose of understanding and improving the model. It should be emphasized that for the purpose of model validation these statistical tests are critical in order to determine the cause of the discrepancies between predicted and observed concentrations. Bowne[24] and Javitz and Ruff[23] gave particular emphasis to this approach. In this study, individual algorithm evaluation has not been emphasized. Instead, we have used the approach to identify where the two versions of CRSTER predict different results.

Traditionally scatter diagrams, linear regression and Pearson's correlation coefficient have been used as the first step in algorithm evaluation because all three methods are simple and informative. Two figures are included to illustrate scatter diagrams and linear regression. Figure V-7 illustrates 24-hour average predictions at Liberty Ridge while the Canip Creek predictions are shown in Figure V-8. Both figures show the scatter of the predictions and observations and include superimposed regression lines which represent the least squares linear regression line

Figure V-7

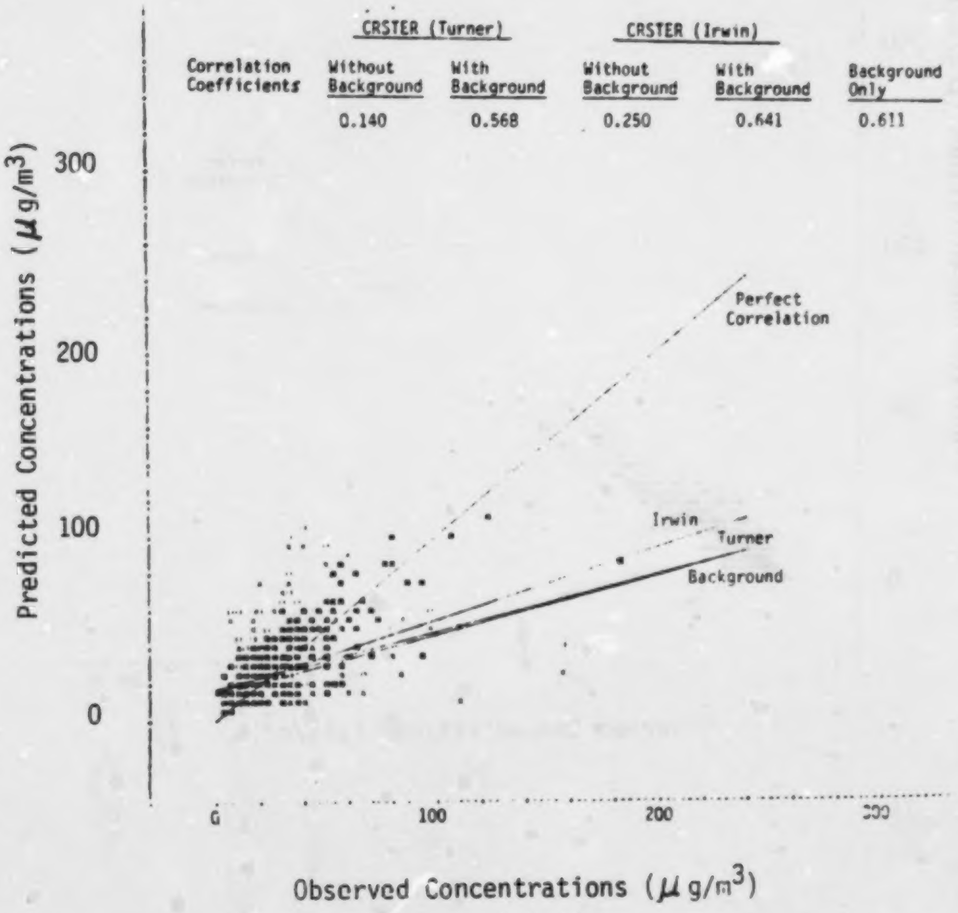
Scatter Plot of 24-Hour Average Concentrations at Liberty Ridge for 1975. Least Squares Regression Lines for CRSTER (Irwin), CRSTER(Turner) and Background Concentrations Versus Observed Concentration are Also Shown. CRSTER(Irwin) Versus Observed Pairs are Shown as 'o' and CRSTER(Turner) Versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.



	CRSTER (Turner)		CRSTER (Irwin)		
Correlation Coefficients	Without Background	With Background	Without Background	With Background	Background Only
	0.0806	0.387	0.0157	0.801	0.897

Figure V-8

Scatter Plot of 24-Hour Average Concentrations at Canip Creek for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations Versus Observed Concentration are Also Shown. CRSTER(Irwin) Versus Observed Pairs Are Shown as 'o' and CRSTER(Turner) Versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.



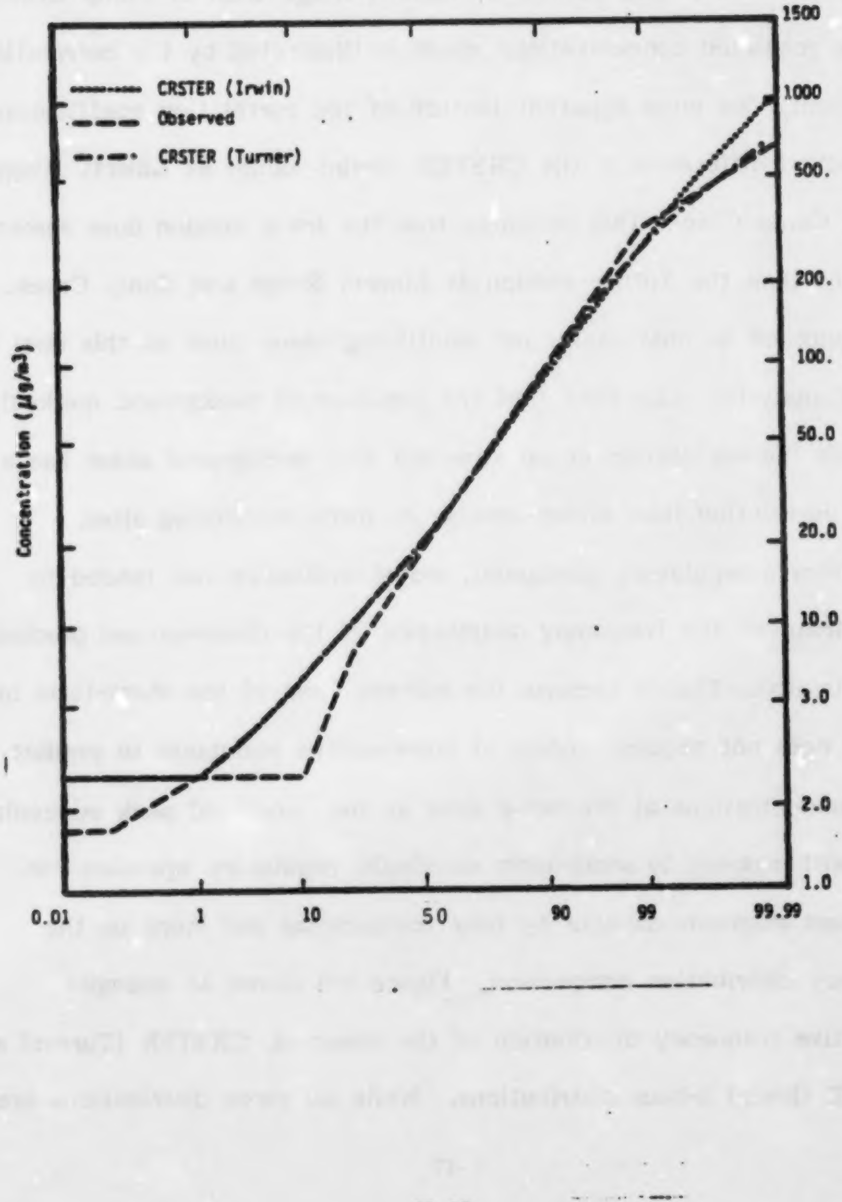
	CRSTER (Turner)		CRSTER (Irwin)		
Correlation Coefficients	Without Background	With Background	Without Background	With Background	Background Only
	0.140	0.568	0.250	0.641	0.611

for the prediction-observation pairs. Two additional lines are drawn for comparison: 1) the perfect correlation line which represents the linear regression line for the background vs observation pairs. At Liberty Ridge note that all three regression lines are closer to the perfect correlation line than at Canip Creek. At these two sites and at all the other sites (shown in Appendix A), CRSTER (Irwin) consistently was closer to the perfect correlation line than CRSTER (Turner).

There also is less scatter at Liberty Ridge than at Canip Creek for the predicted concentrations which is illustrated by the correlation coefficient. The most apparent feature of the correlation coefficients is the marked difference in the CRSTER (Irwin) values at Liberty Ridge and at Canip Creek. This indicates that the Irwin version does something different than the Turner version at Liberty Ridge and Canip Creek. This approach is most useful for identifying cases (such as this one) for further analysis. Also note that the inclusion of background markedly improves the correlation at all sites but that background alone has a higher correlation than either version at three monitoring sites.

From a regulatory standpoint, model evaluation has tended to concentrate on the frequency distribution of the observed and predicted concentrations. This is because the current form of the short-term air quality does not require models of non-reactive pollutants to predict peak concentrations at the same time as the observed peak concentrations. Thus, with respect to short-term standards, regulatory agencies can place less emphasis on hour by hour comparisons and more on the frequency distribution comparison. Figure V-9 shows an example cumulative frequency distribution of the observed, CRSTER (Turner) and CRSTER (Irwin) 3-hour distributions. While all three distributions are

Figure V-9
Bacon Ridge 3-Hour Concentration Cumulative Frequency Distribution in 1975



virtually identical up to the 99th percentile level, the CRSTER (Turner) distribution is closest to the observed distribution thereafter.

The Chi-square test, and nonparametric distribution tests such as the Kolmogorov-Smirnov test or the Mann-Whitney test, are intended to determine whether there are significant differences between the observed and predicted frequency distributions or portions thereof. These frequency distribution tests seem particularly appealing because of the regulatory significance of the upper frequency distribution tail. However, they are primarily sensitive to the bulk of the data, rather than to the tail, so that they were not applied to the extremely skewed data implicit in the single-source situation. Some study of their use is warranted, but was not attempted in this effort.

The differences between CRSTER (Turner) and CRSTER (Irwin) predictions as compared to observations were explored by analyzing the residuals (Predicted + Background - Observed). Figure V-10 shows histograms of CRSTER (Turner) residuals at Bacon Ridge for all hourly prediction-observation pairs and the top 5% pairs while Figure V-11 presents similar histograms for CRSTER (Irwin). Each bar represents residuals in a 10 $\mu g/m^3$ range. The center of the distribution is set at zero. Note that both histograms that consider all hourly pairs are centered around zero, have the most residuals in the zero cell, and are roughly "normal". The dashed line represents the boundaries of 90% of the distribution, i.e. 90% of the hourly pairs occurred between those lines. The top 5% of the pairs have markedly different histograms from those obtained when all residuals were analyzed. Both the CRSTER (Turner) and CRSTER (Irwin) histograms (5%) have the majority of values near -100 $\mu g/m^3$, the median for both histograms is at -100 $\mu g/m^3$, and

Figure V-10. Histogram of CRSTER (Turner) Hourly Residuals for All Hourly Pairs and the Top 5% Pairs (Bacon Ridge). Boundaries of 90% of the Distribution are labelled by dashed lines.

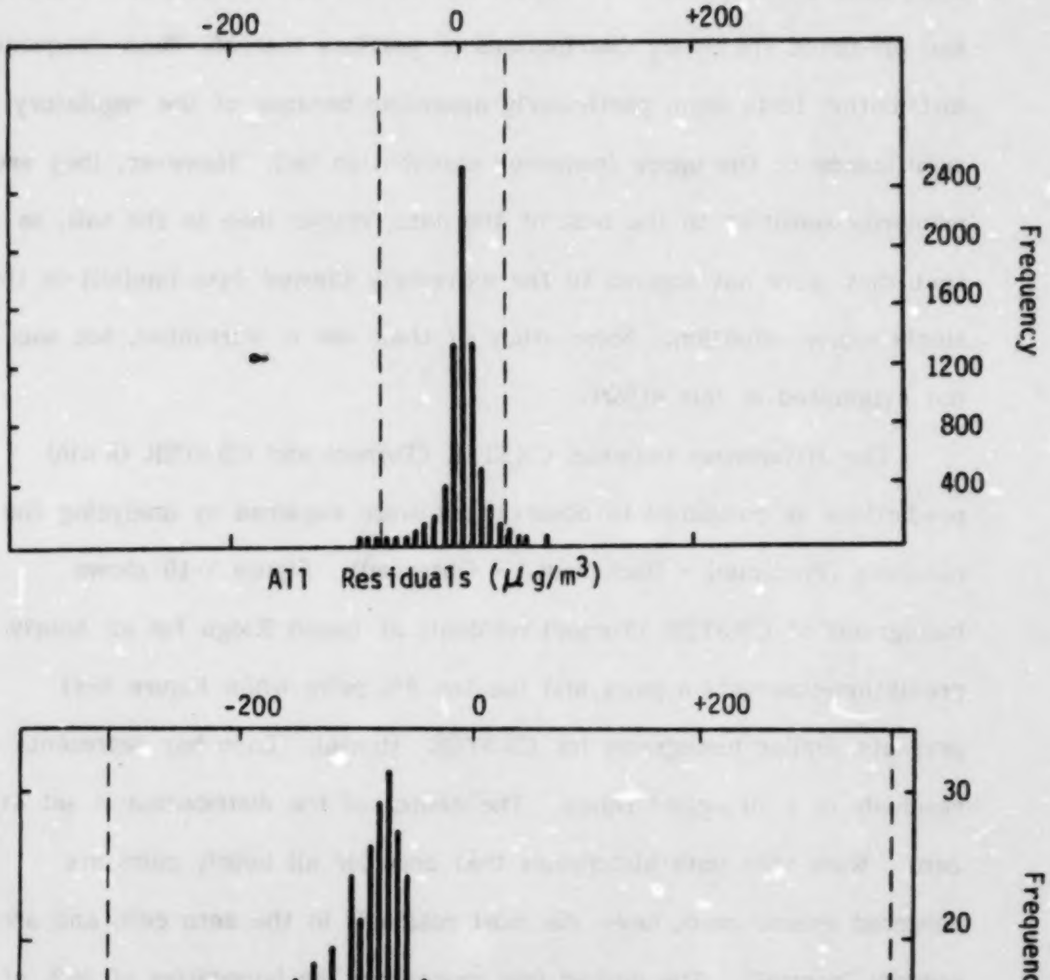
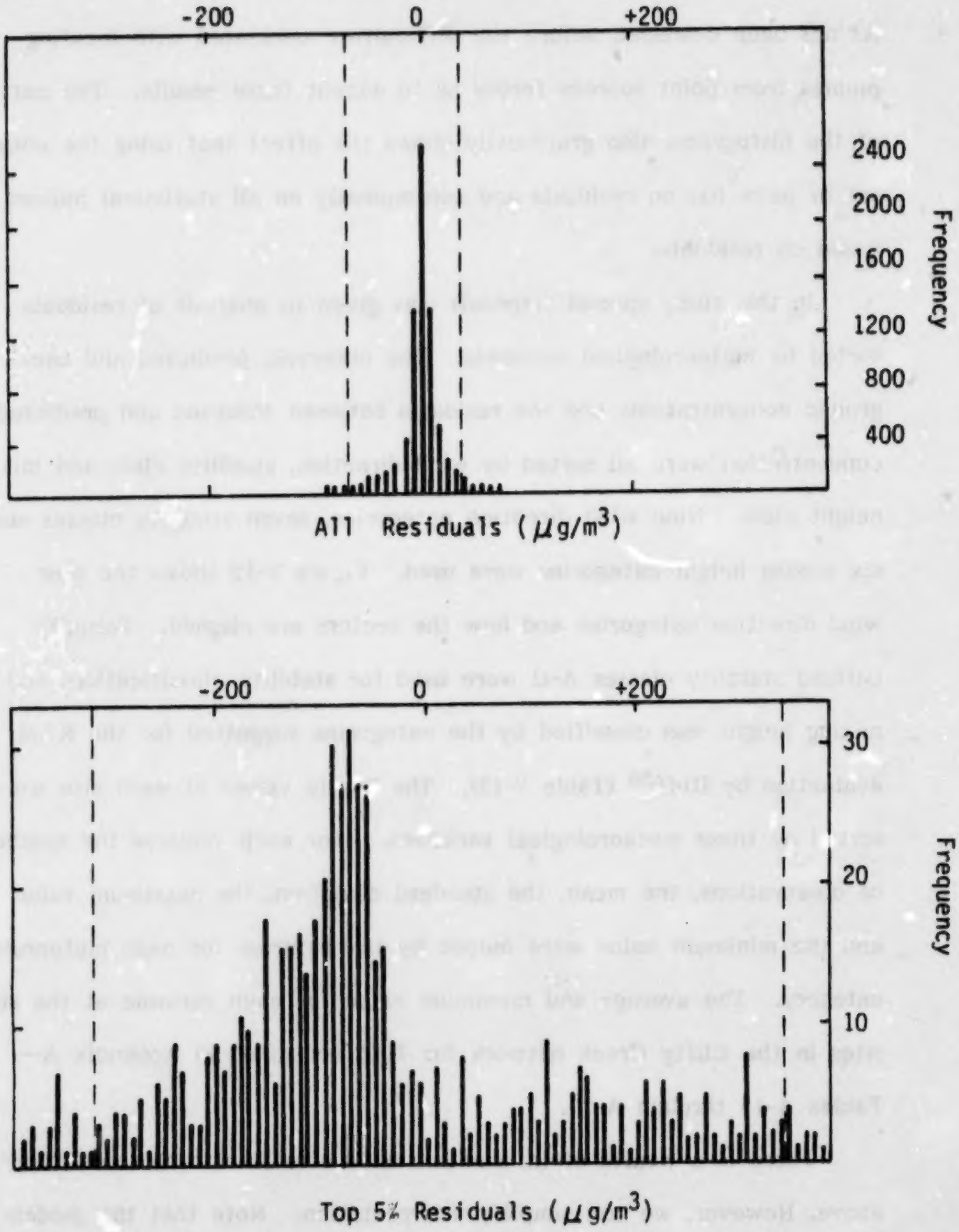


Figure V-11. Histogram of CRSTER(Irwin) Hourly Residuals for All Hourly Pairs and the Top 5% Pairs (Bacon Ridge). Boundaries of 90% of the Distribution are labelled by dashed lines.



the 90% boundaries are much wider than for all pairs. CRSTER (Turner) is spread out a little more than CRSTER (Irwin) at this site. Qualitatively all the other sites had similar histograms. This pattern indicates that both models predict peak concentrations poorly on an hour to hour basis. As has been discussed before the difficulties associated with locating plumes from point sources forces us to accept these results. The pattern of the histograms also graphically shows the effect that using the entire set of pairs has on residuals and consequently on all statistical indices based on residuals.

In this study special emphasis was given to analysis of residuals sorted by meteorological variables. The observed, predicted and background concentrations and the residuals between observed and predicted concentration were all sorted by wind direction, stability class and mixing height class. Nine wind direction categories, seven stability classes and six mixing height categories were used. Figure V-12 shows the nine wind direction categories and how the sectors are aligned. Pasquill-Gifford stability classes A-G were used for stability classification, and mixing height was classified by the categories suggested for the RAM evaluation by Ruff[30] (Table V-13). The hourly values at each site were sorted by these meteorological variables. For each variable the number of observations, the mean, the standard deviation, the maximum value and the minimum value were output by the program for each meteorological category. The average and maximum value for each variable at the six sites in the Clifty Creek network for 1975 are given in Appendix A—Tables A-15 through A-21.

There is a wealth of information on the residual tables described above. However, we can simplify interpretation. Note that the models

Figure V-12. Wind Direction Sorting Categories

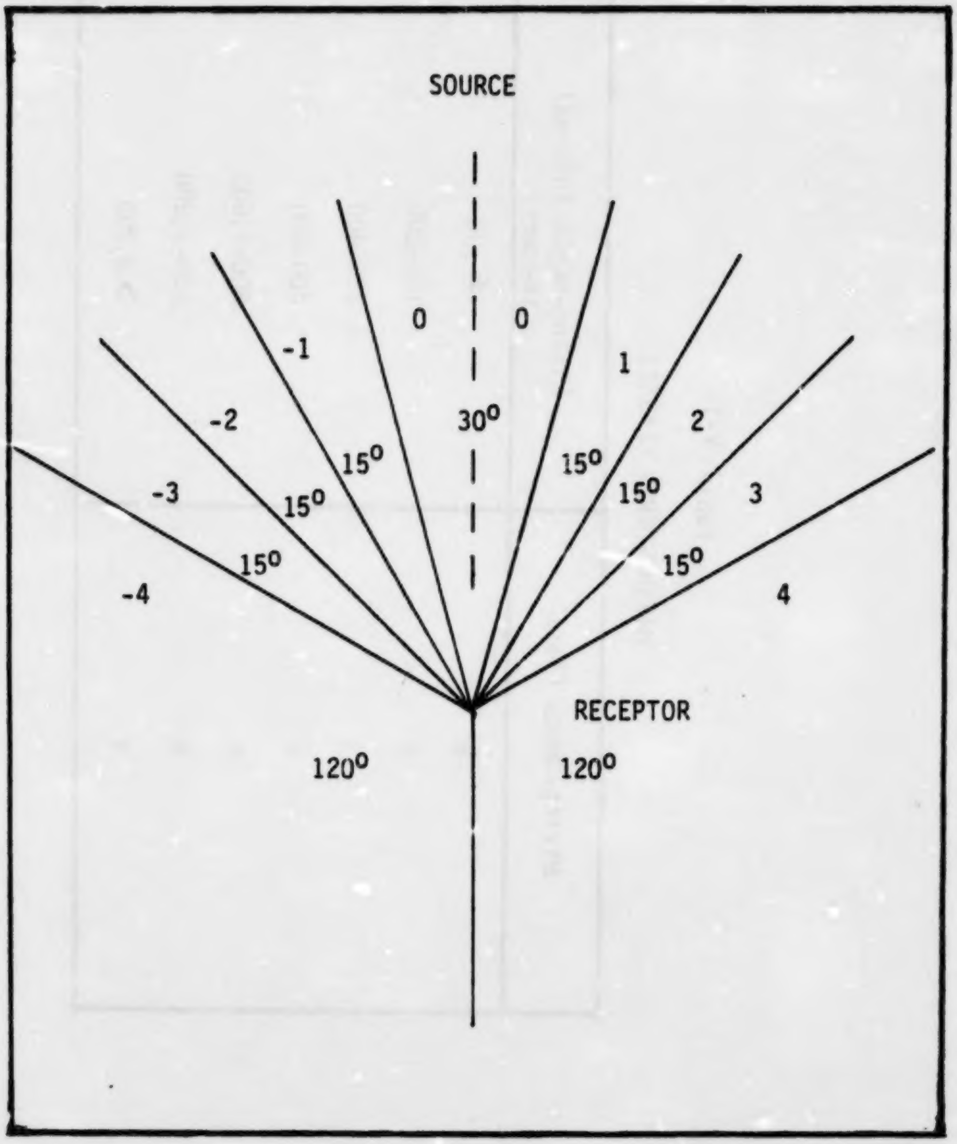

SOURCE
0
0
-1
1
-2
2
30°
15°
15°
-3
15°
15°
3
15°
15°
-4
4
RECEPTOR
120°
120°

Table V-13.

MIXING-DEPTH CLASSES

Mixing-Depth Class	Mixing-Depth Interval (meters)
1	≤ 100
2	100-200
3	200-400
4	400-800
5	800-1,600
6	1,600-3,200
7	> 3,200

predict significant impacts in only 3 wind direction categories. This implies that the residuals in the other categories are only a function of background and observed concentration, so we can consider just the 3 categories with significant impacts and reduce the effect of hours when no impact is possible. For those 3 wind direction categories, we hope that the observed concentration is primarily due to transport of material directly from the source to the monitor, at least for the higher observed concentration values. This approach could possibly be extended so that monitoring network data from several generating station networks could be combined for model evaluation. Finally, note that the average of the residuals is equivalent to the systemetic bias performance measure.

Table V-14 summarizes the average residuals for hours where the models can predict impacts. At all but the Canip Creek site the Turner version has less bias than the Irwin version and CRSTER (Turner) predicted lower concentrations than CRSTER (Irwin) at all six sites. Both versions overpredict concentrations for A and B stabilities, and CRSTER (Turner) underpredicts for D stability. CRSTER (Irwin) predicted greater concentrations than CRSTER (Turner) for stability class E at all 6 sites. For the mixing height categories both models tend to underpredict for low mixing heights and overpredict for the larger classes. CRSTER (Irwin) predicts greater concentrations than CRSTER (Turner) for the 3 largest mixing height categories. Also note that both versions overpredict for the largest mixing height class at all but the Liberty Ridge site.

The next step in this analysis is to examine the joint stability class and mixing height average residuals. However, we begin to run into the original problem of too many numbers unless we consider only some small feature of the distribution. For example, consider only the

Table V-14. Clifty Creek (1975)

Residuals ($\mu g/m^3$) For Only Hours With Impact Possible (based on wind direction)
Residuals are Predicted Plus Background Minus Observed

	Bacon Ridge	Rykers Ridge	Hebron Church	North Madison	Liberty Ridge	Canip Creek
			TURNER			
All	-4.27	-0.978	14.6	-7.30	-6.32	-13.8
Stability						
A	84.1	298.	81.7	456.	302.	34.0
B	24.2	121.	35.2	189.	104.	49.6
C	1.66	25.5	75.6	64.6	-17.8	-34.0
D	-12.9	-18.6	-1.20	-33.0	-15.7	-30.5
E	16.3	3.62	39.4	-18.0	-6.99	1.44
F	-4.45	-7.64	-1.69	-10.7	---	---
G	---	---	---	---	---	--
Mixing Height						
1	-28.8	---	-4.97	-12.1	-28.0	-48.7
2	---	-25.7	8.69	9.56	-6.84	-34.5
3	-11.4	-33.1	-1.92	-43.4	0.246	-37.4
4	-14.6	-19.8	-15.1	-15.5	-3.15	-22.5
5	-8.08	-13.7	19.0	8.99	-5.98	5.88
6	18.7	5.32	13.8	12.5	-0.862	7.83

Table V-14. (cont'd)

IRWIN

All Stability	-4.56	10.9	26.7	38.3	21.6	-6.28
A	79.6	194.	63.7	329.	452.	8.55
B	11.4	82.6	16.4	142.	173.	23.3
C	-6.44	36.3	34.9	133.	97.1	60.2
D	-14.1	1.92	10.0	17.4	1.03	-21.0
E	30.3	12.1	113.	73.9	3.28	5.60
F	-4.94	-7.49	-0.606	-10.5	---	---
G	---	---	---	---	---	---
Mixing Height						
1	-27.0	---	16.0	-6.27	-32.4	-29.8
2	---	-25.5	21.4	-9.56	-6.95	-21.6
3	8.56	-20.3	-16.0	-38.0	-19.5	-32.5
4	-2.23	-11.4	25.5	-4.58	-2.47	27.5
5	28.6	-7.03	36.1	23.4	-3.37	59.8
6	68.4	13.2	26.5	23.9	-1.15	52.7

overprediction at Bacon Ridge for the mixing height class 6. If we compare the Bacon Ridge residuals to those for one of the other sites, say North Madison, then we may be able to see a pattern that can show the cause for the overprediction at Bacon Ridge (Table V-15). Table V-15 lists the average residuals at those two sites for those stability class - mixing height categories that had model impacts and more than 5 hours with those conditions. Note that the North Madison site has larger CRSTER Turner and Irwin overpredictions during unstable conditions (stability classes A, B, and C) than Bacon Ridge. For neutral and stable conditions, CRSTER (Turner) predicts lower concentrations at North Madison than at Bacon Ridge, whereas, CRSTER (Irwin) predicts larger concentrations at North Madison for all but stability class F. Note first that the relatively small average residual for all hours combined must occur because the overpredictions and underpredictions cancel each other when averaged. The overprediction for mixing height category 6 occurs because there are relatively more occurrences of unstable conditions with their overpredictions.

The residuals can also be used to compare the differences between the two versions of the model at a single site. Table V-16 lists the average residual difference [CRSTER (Turner) minus CRSTER (Irwin)] at the North Madison site. Categories with dashes represent conditions when no significant model impacts were predicted or conditions when no observations were made. At the North Madison site in 1975, CRSTER (Turner) predicted greater concentrations than CRSTER (Irwin) for 4 of 8 unstable (A, B and C classes) categories in the table. Note that the residuals for stability classes A and B summed over all mixing height categories and for the smallest mixing height categories indicate that CRSTER (Turner)

Table V-15. Average Residuals (μg/m^3) for Hours with Impact at Bacon Ridge and North Madison for 1975 Sorted by Stability and Mixing Height. Only Classes with Greater than Five Observations Were Included.

Stability	Mixing Height	Turner		Irwin	
		Bacon Ridge	North Madison	Bacon Ridge	North Madison
A	5	116.	542.	108.	328.
B	4	-23.6	-33.9	-42.8	-66.2
B	5	38.0	273.	20.2	203.
B	6	39.0	267.	36.6	243.
C	2	---	---	---	---
C	3	-19.5	---	-19.5	---
C	4	-3.40	58.8	-23.3	-4.95
C	5	-0.434	123.	-5.57	264.
C	6	14.8	61.4	11.1	213.
D	1	---	---	---	---
D	2	---	---	---	---
D	3	2.84	-23.2	-22.4	-19.1
D	4	-8.37	-38.9	-7.92	25.7
D	5	-17.4	-28.6	-14.7	33.6
D	6	-16.0	-20.6	-14.6	13.3
E	1	9.35	-21.6	-7.44	65.6
E	2	23.8	-5.74	24.3	56.8
E	3	5.5	-7.84	5.58	15.3
E	4	49.0	-16.0	76.3	123.
E	5	4.50	-21.4	22.4	54.1
E	6	10.9	-15.5	11.4	89.4
F	1	-10.3	---	-13.8	---
F	3	---	---	---	---
F	4	-1.74	-5.22	-1.51	-9.22
F	5	-2.28	-9.63	-2.99	-12.6
F	6	-7.81	-12.8	-8.11	-9.51
G	4	---		---	
G	5	---		---	
G	6	---		---	

Table V-16. Average Residual ($\mu g/m^3$) Difference (Turner-Irwin) at the North Madison Monitoring Site for Hours With Impact Only. (1975)

MIXING HEIGHT CATEGORY

STABILITY CLASS	6	5	4	3	2	1	$\sum$
A	-90	210	---	---	---	---	130
B	30	70	-32	---	---	---	50
C	-149	-140	64	---	---	---	-65
D	-34	-63	-65	-4	---	---	-50
E	-104	-75	-136	-22.8	-62.7	-88	-92
F	---	---	---	---	---	---	---
G	---	---	---	---	---	---	---
$\sum$	-102	-94	-65	10	27.9	37.8	

predicted concentrations are greater than CRSTER (Irwin). CRSTER (Irwin) consistently predicted concentrations greater than CRSTER (Turner) for E stability, and for the largest mixing height categories.

The residuals during hours with possible impact from all six sites can be combined in one data set. Table V-17 lists the frequency (number of hours), maximum concentration, average and standard deviation of the observed, background, CRSTER (Turner), CRSTER (Irwin), and the residuals for those periods in 1975 when the wind direction was within 30° of the plant-receptor centerline for the six sites in the Clifty Creek monitoring network. Note in particular the maximum concentration column for the observed and predicted concentrations. The maximum observed concentration peaks sharply for mixing height category 3 and stability class C. Both versions of CRSTER predict higher concentrations in the adjacent categories, i.e. relatively high concentrations occur in several categories. CRSTER (Irwin) predicts a peak in stability class C but CRSTER (Turner) predicts its peak in class B. Neither model predicts the peak in the same stability and mixing height category as the observed peak. Note that peak background concentrations occur during D stability. This increases the relative importance of background for longer averaging times in which D stability becomes more important.

The relative differences between model versions are shown in Table V-18. Note that this Table is similar to Table V-16 except that the data from all monitors is included in the analysis. CRSTER (Turner) predicts concentrations greater than CRSTER (Irwin) only in stability classes A and B, but even then CRSTER (Irwin) predicts larger values for the largest mixing height class. Three other features of the table are evident: CRSTER (Irwin) predicts larger numbers than CRSTER (Turner)

Table V-17

Summary Statistics For Hours During 1975 Where Impacts Were Possible (Wind Direction Was Within 30^0 of the Source Receptor Centerline) For All Six Stations of the Clifty Creek Monitoring Network Combined

Stability Class	Mixing Height Category	Observed Without Background Included				Background				CRSTER (Irwin) Predicted Without Background	
		Frequency*	Maximum ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Frequency	Maximum ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)
ALL	ALL	11636	1670.	31.1	85.6	2689	308.	32.7	33.5	15.1	151.
	1	234	689.	20.8	89.2	56	104.	23.5	26.2	-14.1	108.
	2	295	621.	18.9	67.5	64	217.	40.8	39.3	-7.4	103.
	3	806	1670.	35.2	105.	190	112.	26.6	24.5	-22.6	122.
	4	3272	637.	32.8	82.7	736	236.	37.8	36.3	8.2	137.
	5	4875	770.	33.1	90.0	1128	308.	34.0	34.8	23.8	167.
	6	2154	792.	24.8	72.4	515	193.	24.9	26.7	26.5	149.
A		60	352.	43.6	95.0	16	96.6	36.7	25.6	127.	217.
B		471	792.	65.5	138.	110	185.	44.5	37.0	64.7	250.
C		1251	1670.	54.1	124.	293	217.	40.0	36.6	53.3	244.
D		6377	770.	35.2	85.6	1451	308.	31.9	33.3	-0.5	120.
E		1589	655.	15.5	59.0	364	303.	14.4	35.6	53.7	191.
F		1282	467.	6.1	30.3	311	183.	28.5	28.8	-4.6	31.4
G		606	254.	8.3	24.8	144	142.	21.4	24.6	-8.3	24.6

Table V-17 Continued

Stability Class	Mixing Height Category	Frequency*	CRSTER (Turner) Residual			CRSTER (Irwin) Residual			CRSTER (Turner) Predicted Without Background	
			Maximum ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Average ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)
ALL	ALL	12995	1340.	30.4	113.	1530.	47.3	142.	-1.64	131.
	1	250	311.	4.5	28.1	520.	13.8	63.6	-24.0	93.4
	2	341	425.	5.1	40.7	793.	10.5	71.5	-13.3	81.0
	3	674	751.	16.0	82.4	991.	12.5	76.6	-19.3	120.
	4	3454	1320.	25.7	101.	1180.	41.4	131.	-8.2	120.
	5	5384	1330.	37.1	126.	1520	50.4	159.	3.0	143.
	6	2692	1340.	33.5	118.	1420	51.6	146.	8.4	125.
A		68	1300.	214.	282.	730.	169.	193.	174.	310.
B		546	1340	143.	257.	1210.	127.	220.	82.4	290.
C		1484	1320	90.1	199.	1530.	104.	215.	36.8	229.
D		6939	770.	18.1	70.8	1050.	36.2	110.	-18.1	98.5
E		1781	693.	23.4	84.3	1100.	71.1	191.	7.8	102.
F		1460	80.0	1.3	7.1	190.	1.5	8.8	-4.8	31.1
G		717	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	24.6

*Frequency of the Residuals is equal to frequency of Observed without Background Included
Frequency of CRSTER (Irwin) is equal to frequency of CRSTER (Turner)

Table V-18

Average Residual Difference [CRSTER (Turner)-CRSTER (Irwin)] at all six Clifty Creek Monitors During the 1975 Periods with Possible Impact Only

Stability Class	6	5	4	3	2	1	∑
A	18 (21)	69 (36)	- (0)	- (0)	* (3)	- (0)	47. (60)
B	-14 (139)	36.5 (230)	23.3 (851)	* (6)	* (7)	* (4)	17.7 (471)
C	-52.8 (305)	-40.5 (521)	52.3 (316)	* (75)	* (25)	* (9)	-16.5 (1251)
D	-12.4 (670)	-23.2 (2485)	-22.0 (2269)	5.6 (633)	* (186)	* (134)	-17.6 (6377)
E	-40.2 (320)	-42.7 (776)	-65.1 (336)	-16.2 (56)	-34.4 (51)	-48.7 (48)	-45.9 (1589)
F	-0.1 (479)	-0.2 (524)	-0.8 (185)	0.1 (32)	0.6 (23)	0.7 (39)	-0.2 (1282)
G	* (220)	* (303)	* (79)	* (4)	- (0)	- (0)	- (606)
∑	-18.1 (2154)	-20.8 (4875)	-16.4 (3272)	3.3 (806)	-5.9 (295)	-9.9 (234)	-16.7 (11636)

Mixing Height Category

for E stability, both models predict stability class F very well, and neither model predicts any impacts for stability class G.

Although it should be possible to say which version of CRSTER predicts concentrations better it must be emphasized that these results are limited both in total numbers (only 11600 hourly concentration residuals are considered) and in the spatial deployment of the monitors. Therefore any final conclusions based on these statisitcs would be premature. However, CRSTER (Irwin) does appear to a slightly better job for peak hourly concentration estimates. If the average residual for all periods is considered CRSTER (Turner) does better. CRSTER (Irwin) predicts stability classes A, B, D and F better (residuals closer to zero) than CRSTER (Turner). Note that both models are conservative (residuals are positive) for stability classes A, B, C, and E which are the classes where maximum impacts are normally found. However, neither model predicted peak impacts for the same stability and mixing height conditions as was observed. The original sorted data can be used to compare the meteorological conditions that cause maximum predicted and observed concentrations. Table V-19 lists the wind direction, stability class and mixing height category for the peak observed, background and predicted concentrations at each site in 1975. It is obvious that the models do not necessarily predict peak concentrations at the same time or for the same conditions as is observed. Also note that the models predict peak concentrations for different conditions. However it should be noted that peak predictions are an extreme event and that both meteorological and emission characteristics are important factors in the occurrence of peak events. Therefore, we should look at more of the high concentrations. In the next section the top 25 concentrations in the entire network are used. Finally, the only consistency in the

Table V-19. Meteorological Conditions Associated With Maximum Observed, Background and Predicted Concentrations (Clifty Creek Network, 1975)

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Observed Peak						
Wind Direction	3	0	0	4	-4	2
Stability Class	C	D	C	D	C	F
Mixing Height	4	5	3	5	4	4
Turner Peak						
Wind Direction	0	0	0	0	0	0
Stability Class	B	B,C*	B	C	B	B
Mixing Height	5	4,5*	5	4	6	5
Irwin Peak						
Wind Direction	0	0	0	0	0	0
Stability Class	E	C	C	E	C	B
Mixing Height	4	5	5	4	5	5
Background Peak						
Wind Direction	-1	-3	0	0	-4	-4
Stability Class	D	D	D	D	D	D
Mixing Height	5	5	5	5	5	5

*Two values of peak concentration

table occurs for background peak concentrations which always occurred for D stability and mixing height category 5. The meteorological conditions that lead to concentrations peaks are discussed in more detail in the following section.

VI. CHARACTERISTICS OF OBSERVED AND CALCULATED 3-HOUR AND 24-HOUR EPISODES

A. Episode Analysis Procedures

For each of the 4 monitoring networks the 25 highest measured and calculated 3-hour and 24-hour SO_2 concentrations were retrieved for the years 1975 and 1976. The retrieval was carried out considering all receptors as a group. In the selection of episodes duplicate time periods were avoided. Calculated episodes were retrieved from both CRSTER (Turner) and CRSTER (Irwin) model output for the full set of 360 model receptors (36 directions at 10 distances downwind) and the set of model receptors corresponding to the actual SO_2 monitoring locations. For the Muskingum network only 6 receptors, in addition to the 4 actual monitoring locations, were used since a multiple source dispersion calculation was required for this network. For the Gavin-Kyger-Sporn network only the 11 actual monitoring locations were used in the model calculations. The receptor and source locations and elevations for these last two networks are given in Table III-1(b). Tabulations of the dates, concentrations and receptor locations of these measured and calculated episodes are given in Appendix B. For each episode period the following information is retrieved:

- Hourly and episode average SO_2 concentrations ($\mu g/m^3$) at each receptor
- Hourly ambient temperature (K)
- Hourly wind speed (m/s) and wind flow vector (degrees from north)
- Hourly temperature difference (K/100m)
- Hourly P-G-T stability class (A-F)
- Hourly interpolated mixing height (m)

- Hourly SO_2 emissions (g/sec), gas exit velocity (m/sec) and gas temperature (K) for each stack

In Figures VI-1 through VI-4, the actual 1975 and 1976 combined frequency distribution of episodes are plotted for the following selected parameters: stability class for the peak concentration hour, peak concentration hour wind speed and peak concentration hour. In addition, the frequency of episodes as a function of source-receptor distance is also displayed. For each frequency distribution, the parameter values associated with the highest and second highest concentration for each of the 2 years are indicated as follows:

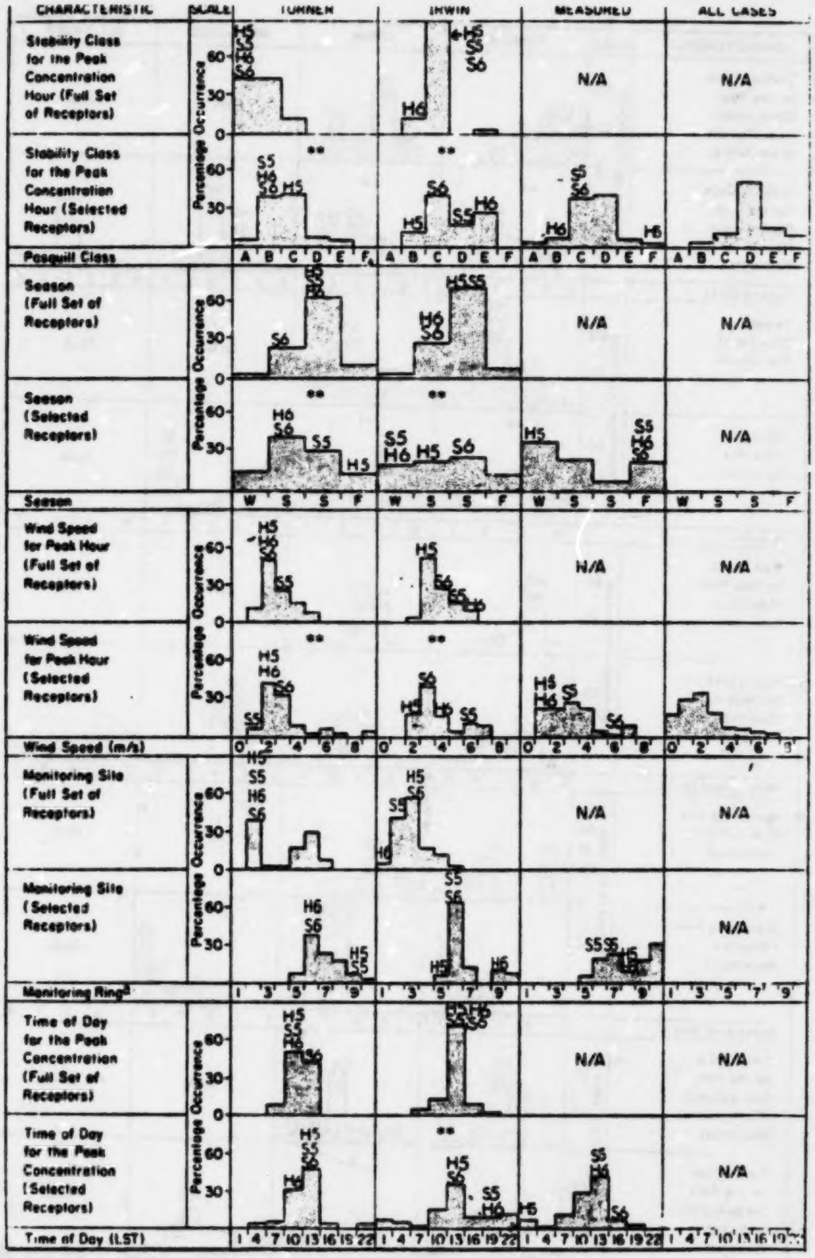
H5=highest concentration episode for 1975
S5=second-highest concentration episode for 1975
H6=highest concentration episode for 1976
S6=second-highest concentration episode for 1976

In the case of the episode parameter distributions for selected receptors, an indication is given as to whether the measured and calculated distributions (except for monitoring site) are different to the 95 or 99 percent level of statistical significance. The chi square test was used for testing the level of significance. In this case the level of significance indicates the confidence we have in rejecting the null hypothesis that both data sets come from the same distribution, with the observed differences due to chance. In other words, the differences between the significantly different pairs are probably due to some substantive effect, rather than random error. Most of the measured and calculated distributions were found to be significantly different in terms of this definition.

B. Episode Analysis for Clifty Creek

The characteristics of the periods having the yearly highest 25 measured and calculated 3-hour and 24-hour SO_2 concentrations were

Figure VI-1(a). Distribution of Characteristics for the 25 Highest Measured and Calculated 3-Hour SO_2 Concentrations at Clifty Creek (data for 1975-76 combined).

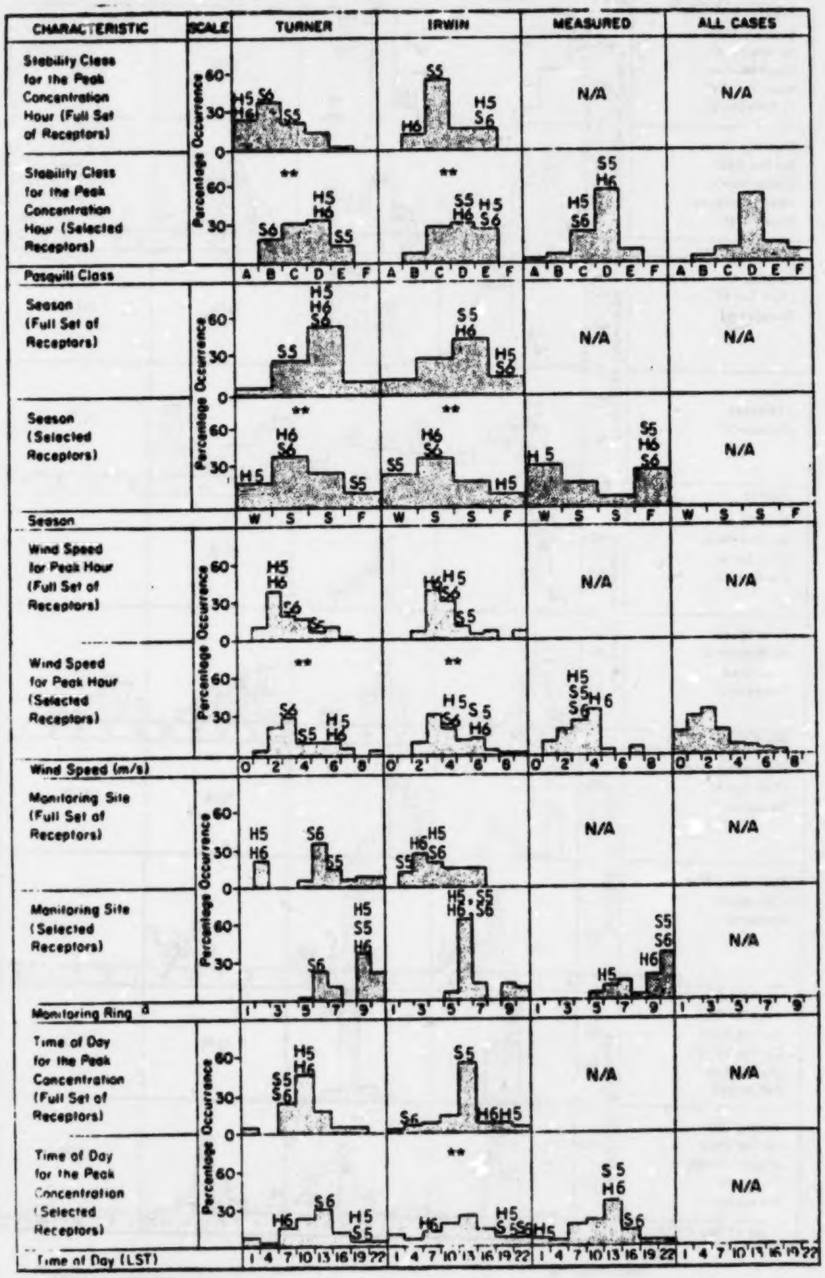


a Monitoring Ring

1 1.0 km downwind
2. 1.5 km downwind
3. 2.0 km downwind
4 2.5 km downwind
5. 3.06 km downwind (Liberty Ridge Monitor)
6 4.51 km downwind (North Madison Monitor)
7. 7.40 km downwind (Rykers Ridge Monitor)
8 8.05 km downwind (Conip Creek Monitor)
9. 11.58 km downwind (Hebron Church Monitor)
10. 14.96 km downwind (Bucan Ridge Monitor)

* = measured and calculated distributions significantly different to 95 percent
** = measured and calculated distributions significantly different to 99 percent

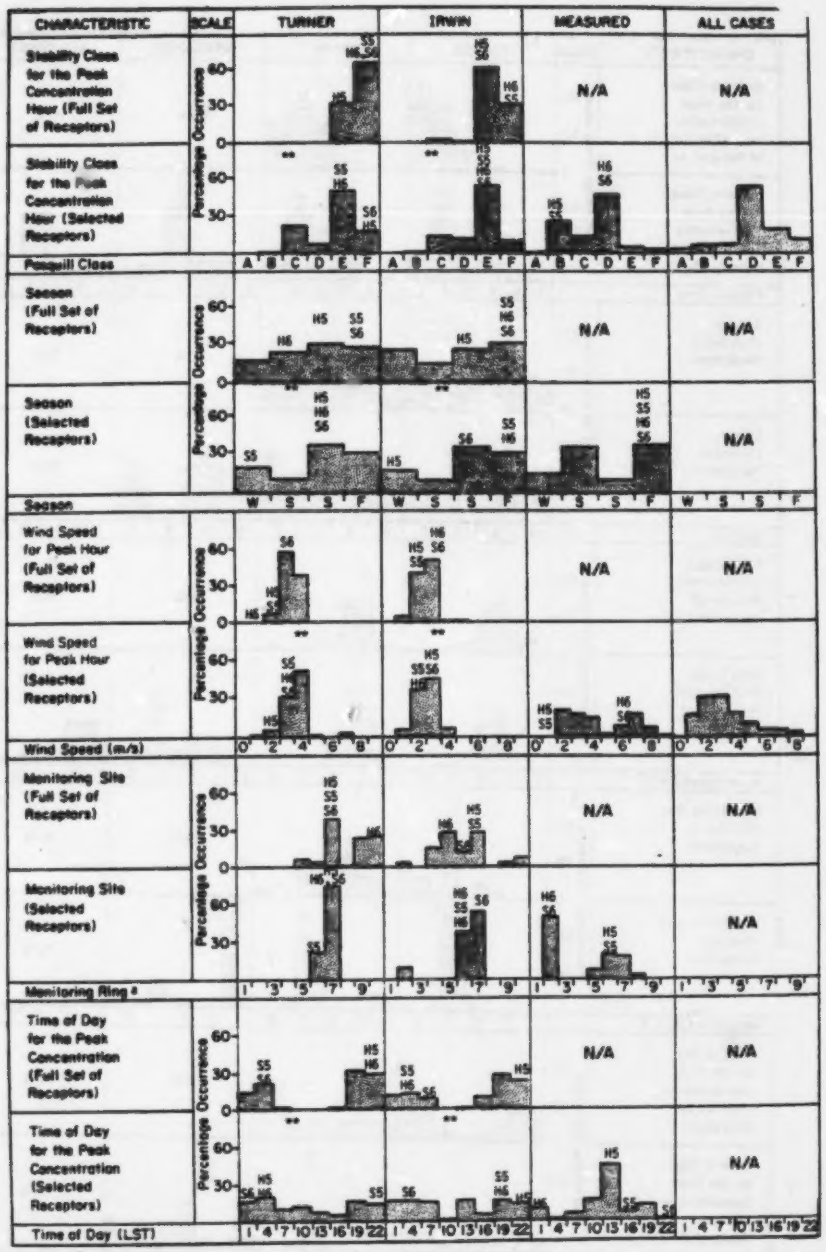
Figure VI-1(b). Distribution of Characteristics for the 25 Highest Measured and Calculated 24-Hour SO_2 Concentrations at Clifty Creek (data for 1975-76 combined).



[a] Monitoring Ring

1 1.0 km downwind
2 1.5 km downwind
3 2.0 km downwind
4 2.5 km downwind
5 3.06 km downwind (Liberty Ridge Monitor)
6 4.51 km downwind (North Madison Monitor)
7 7.40 km downwind (Rykers Ridge Monitor)
8 8.05 km downwind (Canip Creek Monitor)
9 11.58 km downwind (Hebron Church Monitor)
10 14.96 km downwind (Bacon Ridge Monitor)

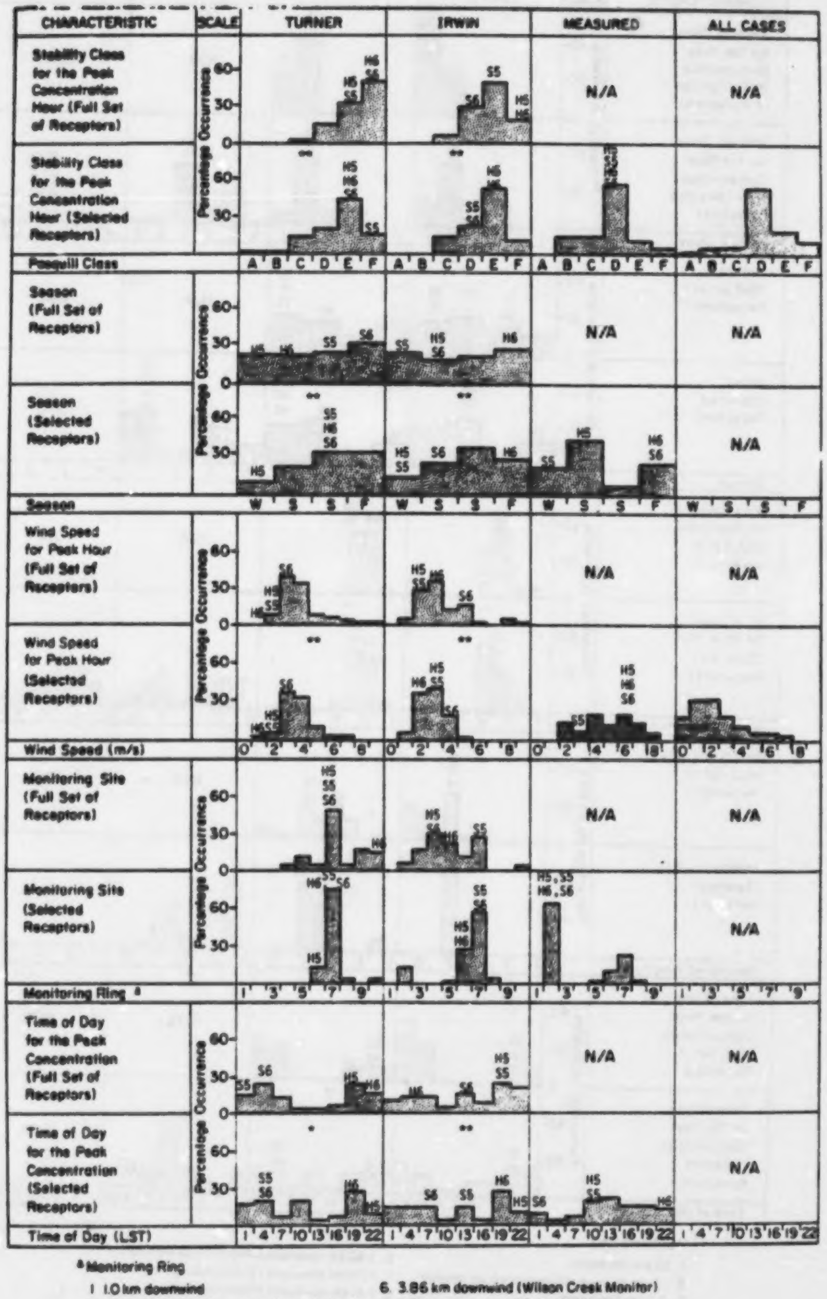
Figure VI-2(a). Distribution of Characteristics for the 25 Highest Measured and Calculated 3-Hour SO_2 Concentrations at Tanners Creek (data for 1975-76 combined).



a Monitoring Ring

1. 1.0 km downwind
2. 1.5 km downwind (Lawrenceburg Monitor)
3. 2.0 km downwind
4. 2.5 km downwind
5. 3.70 km downwind (Petersburg Monitor)
6. 3.86 km downwind (Wilson Creek Monitor)
7. 5.79 km downwind (Dutch Hollow)
8. 9.81 km downwind (Elizabethtown)
9. 12.0 km downwind
10. 16.09 km downwind (Kilby Road Monitor)

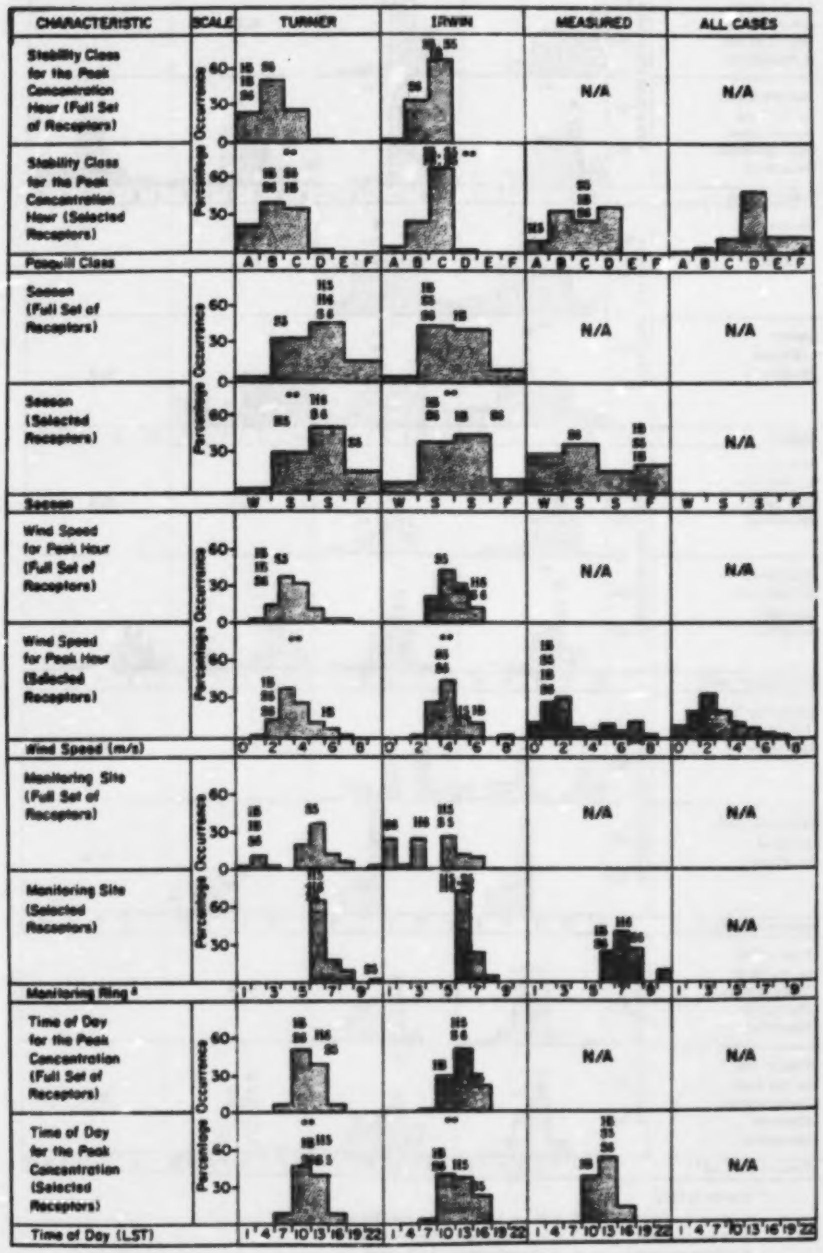
Figure VI-2(b). Distribution of Characteristics for the 25 Highest Measured and Calculated 24-Hour SO_2 Concentrations at Tanners Creek (data for 1975-76 combined).



a Monitoring Ring

1. 1.0 km downwind
2. 1.5 km downwind (Lawrenceburg Monitor)
3. 2.0 km downwind
4. 2.5 km downwind
5. 3.70 km downwind (Petersburg Monitor)
6. 3.86 km downwind (Wilson Creek Monitor)
7. 5.79 km downwind (Dutch Hollow)
8. 9.81 km downwind (Elizabethtown)
9. 12.0 km downwind
10. 16.09 km downwind (Kilby Road Monitor)

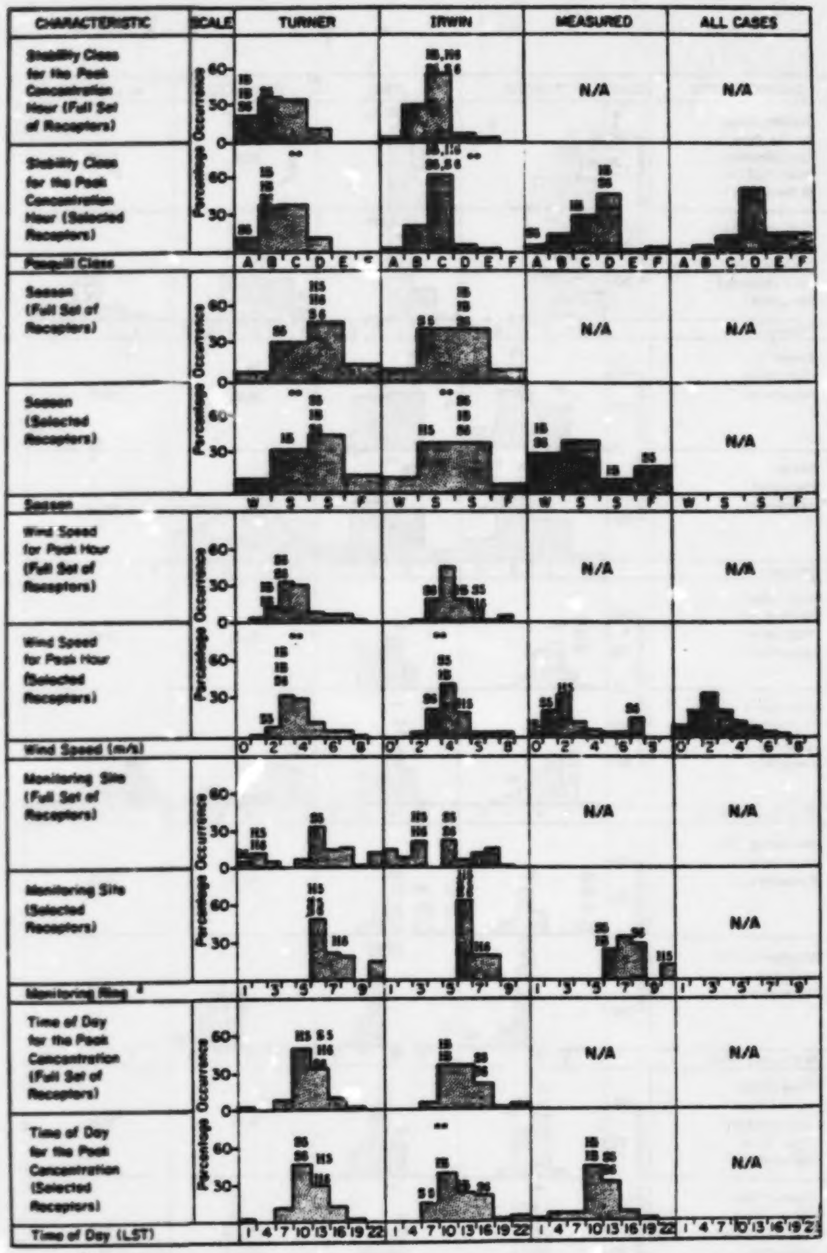
Figure VI-3(a). Distribution of Characteristics for the 25 Highest Measured and Calculated 3-Hour SO_2 Concentrations at Muskingum - (data for 1975-76 combined).



* Monitoring Ring

1. 1.0 km downwind
2. 1.5 km downwind
3. 2.0 km downwind
4. 2.5 km downwind
5. 3.0 km downwind
6. 4.34 km downwind (Hackney Monitor)
7. 5.31 km downwind (Beverly Monitor)
8. 8.05 km downwind (Rich Valley)
9. 12.0 km downwind
10. 19.79 km downwind (Caldwell Monitor)

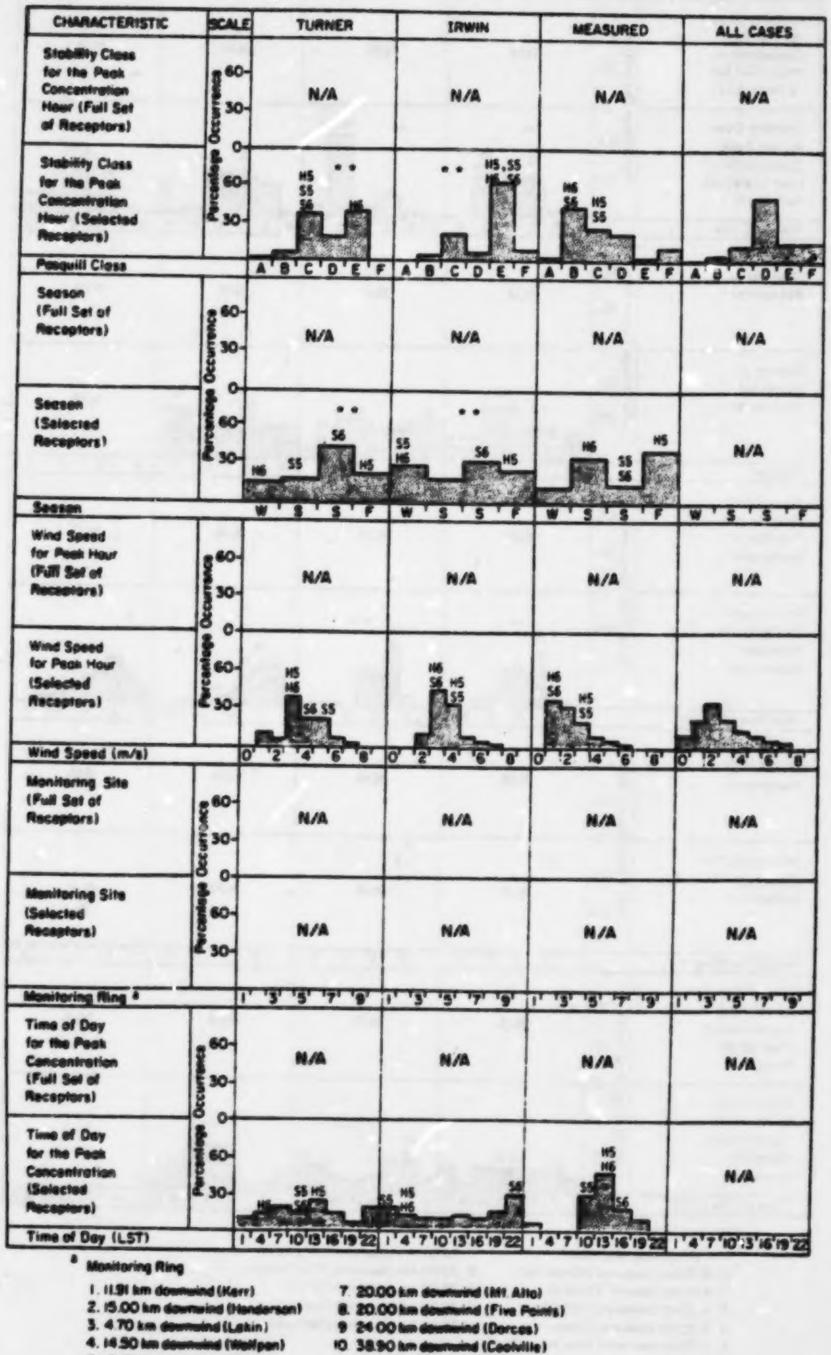
Figure VI-3(b). Distribution of Characteristics for the 25 Highest Measured and Calculated 24-Hour SO_2 Concentrations at Muskingum - (data for 1975-76 Combined).



ª Monitoring Ring

1. 1.0 km downwind
2. 1.5 km downwind
3. 2.0 km downwind
4. 2.5 km downwind
5. 3.0 km downwind
6. 4.34 km downwind (Hackney Monitor)
7. 5.31 km downwind (Beverly Monitor)
8. 8.05 km downwind (Rich Valley)
9. 12.0 km downwind
10. 19.79 km downwind (Coldwell Monitor)

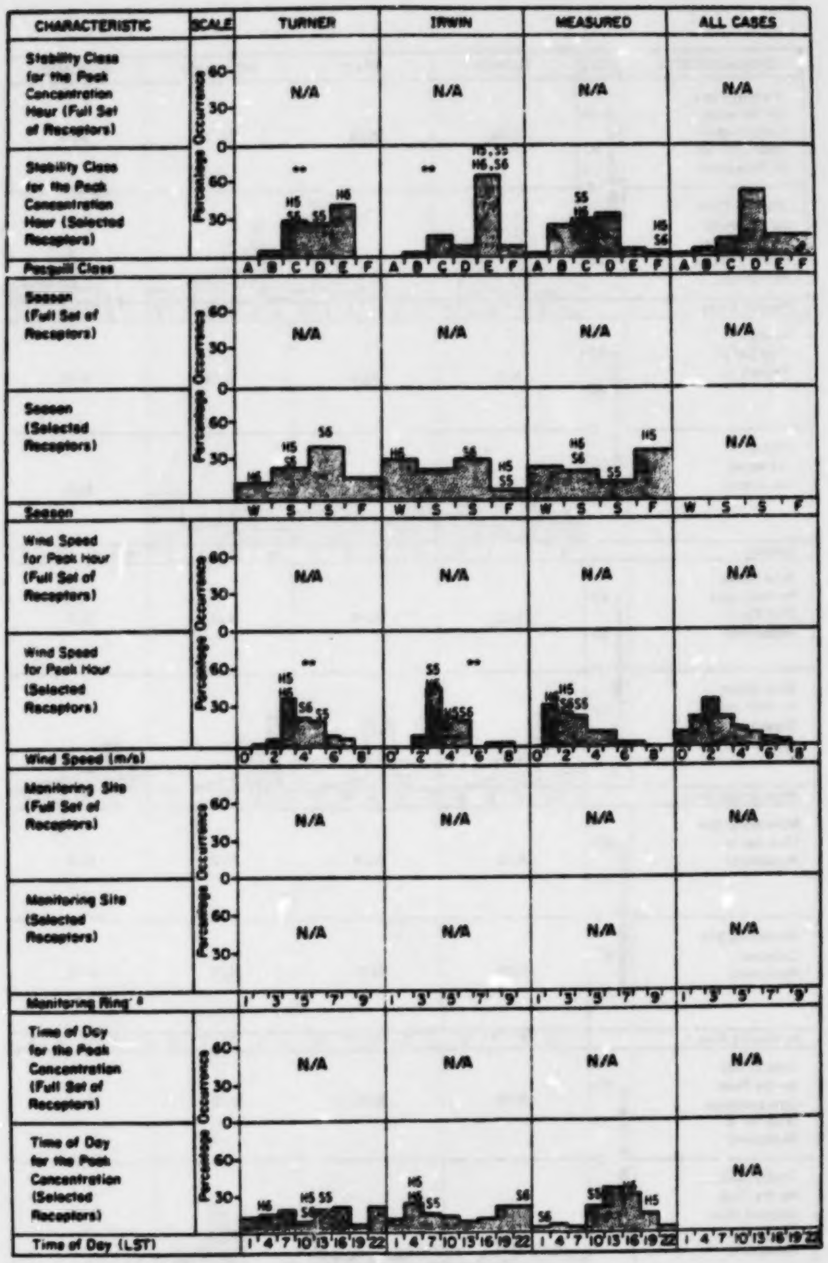
Figure VI-4(a). Distribution of Characteristics for the 25 Highest Measured and Calculated 3-Hour SO_2 Concentrations at Gavin-Kyger-Sporn (data for 1975-76 combined).



a Monitoring Ring

1. 11.91 km downwind (Kerr)
2. 15.00 km downwind (Henderson)
3. 4.70 km downwind (Lakin)
4. 14.50 km downwind (Wolfpen)
5. 12.20 km downwind (Mason)
6. 11.70 km downwind (New Haven)
7. 20.00 km downwind (Mt. Alto)
8. 20.00 km downwind (Five Points)
9. 24.00 km downwind (Dorcas)
10. 38.90 km downwind (Coolville)
11. 33.80 km downwind (Neptune)

Figure VI-4(b). Distribution of Characteristics for the 25 Highest Measured and Calculated 24-Hour SO_2 Concentrations at Gavin-Kyger-Sporn (data for 1975-76 combined).



[a] Monitoring Ring

1. 11.91 km downwind (Kerr)
2. 15.00 km downwind (Henderson)
3. 4.70 km downwind (Lakin)
4. 14.50 km downwind (Wolfpen)
5. 12.20 km downwind (Mason)
6. 11.70 km downwind (New Haven)
7. 20.00 km downwind (Mt. Alto)
8. 20.00 km downwind (Five Points)
9. 24.00 km downwind (Dorcas)
10. 38.90 km downwind (Coolville)
11. 33.80 km downwind (Neptune)

analyzed using combined data for 1975 and 1976. The results of the analysis for the 3-hour and 24-hour averaging times are given in Figures VI-1(a) and (b) respectively. With the full set of 360 receptors, the CRSTER (Turner) calculated 3-hour episodes occur with a peak hour stability class of A or B while the CRSTER (Irwin) episodes occur almost always with C stability for the peak concentration hour. It should be noted that, for both years, the highest and second highest 3-hour calculated episodes for the full set of receptors occurred with a peak concentration hour stability class of A. With the receptors corresponding to the actual measurement sites, the 3-hour CRSTER (Turner) episodes are characterized by stability classes B and C, with a more uniform distribution of classes for CRSTER (Irwin). The measured episodes have peak hour stability classes almost equally divided between C and D. For all hours of the year, D is by far the most frequently occurring class. For the full set of receptors, most CRSTER (Turner) and CRSTER (Irwin) episodes occur during the summer months, consistent with the greater occurrence of stability classes A-C during this time. The distribution of calculated episodes by season for the actual monitors appears more uniform. For the measured episodes there is actually a summer minimum. The distribution of CRSTER (Turner) episodes by receptor ring distance shows a bi-modal distribution with peaks centered at 1.5 km and 4.5 km downwind, while the number of CRSTER (Irwin) episodes shows a single peak at 2 km. The highest and second highest 3-hour CRSTER (Turner) episodes for the full set of receptors for both years occurred at the 1.5 km ring distance. For the actual receptor locations, the CRSTER (Turner) episode distribution peak coincides with the second peak for the full set of receptors. For the CRSTER (Irwin) episodes there is no overlap for the full set of receptors so that the location of monitors does not allow a true comparison of critical conditions for measured and calculated 3-hour concentration episodes. With the exception of the Canip Creek monitor, which is located in the river valley, the number of measured 3-hour episodes actually increases with distance from the plant.

The distributions of 24-hour calculated episodes by peak hour stability class are more uniform than for the 3-hour episodes. The measured distribution of peak hour stability classses is similar to the distribution for all conditions, episode and non-episode. The distribution of measured 24-hour episodes by site is again significantly different from the distribution of episodes calculated by either model.

The mixing heights for the peak concentration hour of the measured episodes are slightly less than for the episodes calculated by either version of CRSTER. This result may be partially due to the assumption of full inversion penetration used by both versions of CRSTER when the calculated plume height is greater than the mixing height estimated for that hour. The peak to mean concentration ratios for the CRSTER (Turner) calculated 3-hour episodes are greater than the ratios for the measured episodes, while those ratios for the CRSTER (Irwin) calculated 3-hour episodes appear to be more realistic. Due primarily to the definition of wind persistence, there did not appear to be any large differences in the wind persistence characteristics between calculated and observed episodes at Clifty Creek or, for that matter, at any of the other 3 networks.

C. Episode Analysis for Tanners Creek

Considering the full set of model receptors, the peak concentration hour stability class for both the CRSTER (Turner) and CRSTER (Irwin) calculated 3-hour episodes is either E or F, with class E more frequently occurring for CRSTER (Irwin) [see Figure VI-2(a)]. These calculated peak hour episode impacts occur during nighttime, consistent with the E and F stability class assignment. This result is due to the fact that a number of the model receptor locations have elevations greater than the plumes emitted from the 3 low stacks at the Tanners Creek plant. These plume impacts under stable conditions are also important in the occurrence of calculated CRSTER (Turner) and CRSTER (Irwin) 3-hour episodes for the actual receptor locations. Most of the observed 3-hour episodes, however, have peak 1-hour concentrations occurring with stability class D. Virtually all of the CRSTER (Turner and Irwin) calculated 3-hour episodes for the selected group of receptors occurred either at Wilson Creek or Dutch Hollow, the 2 monitoring sites with highest elevations in the network. Most of the observed 3-hour episodes occurred at Lawrenceburg, only 1.5 km from the plant and the site with the lowest elevation. A greater fraction of the measured 3-hour episodes have higher wind speeds than do either of the calculated sets of episodes. In Section VII an analysis of 4 of these 3-hour measured episodes at Lawrenceburg shows that the models could not have possibly predicted these high concentrations so close to the plant without the assumption of some stack or building plume downwash.

For both the full and selected set of receptor locations, the peak concentration hour for the CRSTER (Turner) and CRSTER (Irwin) calculated 24-hour episodes is characterized by stable conditions as opposed to neutral stability for the measured episodes. The 24-hour measured episodes are characterized by higher average windspeeds than or either the CRSTER (Turner or Irwin) calculated 24-hour episodes or the measured 3-hour episodes. The measured 24-hour episodes occur primarily at the Lawrenceburg site while the 24-hour episodes calculated by both models occur primarily at Wilson Creek or Dutch Hollow.

D. Episode Analysis for Muskingum

There appears to be little difference between the distribution of calculated 3-hour episodes by peak concentration hour stability class for the full set of receptors and the selected set of receptors. In the case of the Muskingum plant, however, it must be remembered that only 6 additional receptors were used for the full receptor analysis since a multiple source calculation was required for this plant. Five of the 6 additional receptors were located closer to the first stack (Muskingum 1) than any of the 4 actual receptors. The second stack at Muskingum is 0.6 km from the first.

For the selected set of receptors, the CRSTER (Turner) calculated 3-hour episodes are distributed by peak hour stability class almost evenly between classes A, B and C. The CRSTER (Irwin) calculated 3-hour episodes are characterized primarily by a peak hour stability class of C. On the other hand, the measured 3-hour episodes are distributed evenly between peak hour classes of B, C and D with only a few episodes with the peak hour stability class of A. Both models have a tendency to give more summer 3-hour episodes than are actually observed. More of the observed 3-hour episodes are characterized by low peak concentration hour wind speeds than are the episodes calculated by either version of CRSTER. In fact, the highest and second highest 3-hour concentration episodes for both years occur with very low peak hour windspeeds. For the actual receptor locations both versions of CRSTER predict that most of the 3-hour episodes will occur at the receptor closest to the stacks, while the measured 3-hour episodes were more evenly distributed between the Hackney, Beverly and Rich Valley monitors. The distributions of peak hour stability classes for the calculated 24-hour episodes at the selected receptors do not differ greatly from the corresponding 3-hour episode distributions. The measured 24-hour episodes are primarily characterized by a peak concentration hour stability class of D.

E. Episode Analysis for Gavin-Kyger-Sporn

For the Gavin-Kyger-Sporn network, model calculations were performed only for the 11 actual receptor locations. For the CRSTER (Turner) calculated episodes, the peak hour stability classes were primarily C and E with the CRSTER (Irwin) episodes primarily having a peak hour stability class of E. This large fraction of stability E episodes for both models is due to the full height terrain correction along with the lower plume rise calculated under this stability. The most frequently occurring peak hour stability for the measured 3-hour episodes was class B followed closely by classes C and D. There seems to be no clear pattern to the seasonal distribution of measured and calculated episodes. The distribution of measured 3-hour episodes by peak hour wind speed again shows a greater number of episodes with low wind speeds than is obtained by use of either version of CRSTER. The distribution of calculated CRSTER (Turner) and CRSTER (Irwin) 3-hour episodes by peak hour shows a rather uniform distribution throughout the day while the measured distribution has a midday peak. The large fraction of calculated nighttime episodes is consistent with the large fraction of class E episodes. The 24-hour measured and calculated episode distributions are similar to the corresponding 3-hour distributions except that the peak hour stability classes for the measured 24-hour episodes are more evenly distributed among classes B, C and D.

VII. ANALYSIS OF SELECTED 3-HOUR AND 24-HOUR EPISODES

In the last section the characteristics of observed and calculated 3-hour and 24-hour SO_2 concentration episodes were identified through a statistical analysis of the 25 highest episode periods for each network-year. This comparison of episode characteristics has helped not only to identify problems with model assumptions but also to point out differences betweem the Turner and Irwin dispersion calculation schemes with respect to worst case meteorological conditions. An equally important part of the model evaluation is an examination of selected measured episodes to determine whether the models could have possibly described these episodes. For example, a case by case comparison of observed and calculated concentrations could show that one reason for poor model performance is the fact that on site wind data does not give a proper indication of the plume centerline heading. For this case study analysis we have selected the periods corresponding to the measured highest and second highest 3-hour and 24-hour SO_2 concentrations at the 4 networks for both 1975 and 1976.

1. Highest 3-hour Concentration at Clifty Creek in 1975 — January 23, hours 3-5.

During the early morning hours of January 23, three high 1-hour concentrations were recorded at the Canip Creek monitor located 8 km to the east (99 degrees) of the plant. The closest monitoring site at about the same range, Rykers Ridge (7.4 km, 56 degrees) did record a sharp jump in concentration during the third hour, but its magnitude was far less than any of the hourly values reported at Canip Creek. All other sites reported 3-hour average concentrations between 13 and 36 $\mu g/m^3$, compared with the 1075 $\mu g/m^3$ for Canip Creek. Winds during this period were quite light so that the wind flow vectors used by the model do not necessarily provide an indication of the position of the plume axis. Neither the Turner or Irwin versions of CRSTER can give these high values at Canip Creek with the stability class E and F assignment during these 3 hours. It should be noted, however, that the temperature difference reported from the Liberty Ridge tower during this period is more consistent with a neutral stability assignment. The surface weather map for January 23 shows a strong high pressure area centered over the lower Ohio Valley. On the same day, very high early morning SO_2 concentrations were also reported at the TVA Paradise and Johnsonville networks.

2. Second Highest 3-Hour Concentration at Clifty Creek in 1975 — January 24, hours 12-14.

   On January 24, the high pressure system moved to the east of Clifty Creek, setting up a light to moderate persistent wind flow from the south-southwest. The maximum 3-hour SO_2 impact on this day occurred at North Madison (4.5 km, 16 degrees), the nearest monitor northeast of the plant. Stability Class C prevailed for two of the three episode hours. Both versions of CRSTER give zero concentrations during this period because the calculated mixing heights (350 to 400 meters) are below the calculated plume heights.

3. Highest 24-hour Concentration at Clifty Creek in 1975 — January 24.

   On this day the highest 24-hour SO_2 concentration at Clifty Creek for the entire year was recorded at the North Madison monitor, located 2.8 miles north-northeast of the plant. In Figure VII-1, the highest and lowest hourly SO_2 concentrations in the network are shown along with hourly values of stability class, temperature difference and windspeed. Most of the peak hourly concentrations between hours 12 and 17 were measured at the North Madison site. Background concentrations during the morning hours were quite high with Liberty Ridge reporting a 2 a.m. value of 308 $\mu g/m^3$ and a 24-hour average of 122 $\mu g/m^3$. Even after accounting for this background, both versions of CRSTER significantly underpredict the concentration at North Madison on this day. The high SO_2 background concentrations on this day may have been due to the long range transport of SO_2 from the high emission density areas to the southwest of the plant (Louisville, TVA) where it could have accumulated during the stagnation conditions of the previous day. For this day, Figure VII-2 shows the magnitude and spatial distribution of regional background daily average SO_2 concentrations as calculated by a regional grid model. This period of late January 1975 was characterized by SO_2 episodes not only at Clifty Creek but also at the other AEP networks.

4. Second Highest 24-Hour Concentration at Clifty Creek in 1975—October 21.

During the entire day, SO_2 emissions from Clifty Creek impact the Bacon Ridge monitor (40 degrees, 15.0 km), the most distant site from the plant. The observed concentrations at Bacon Ridge are consistent with the persistent moderate winds during this period, but do not show the hourly variation which would be expected as the stability class changes from E to C and then back to Class E at the end of the period. The hour of highest concentration does, however, coincide with the only hour of reported C stability. The sharp reduction in calculated morning mixing height is not reflected in the observed hourly concentrations. The only other site which appears to experience plume impact is the Hebron Church monitor (24 degrees, 11.6 km) during the afternoon. As was the case during the January 24 persistent wind period, the Liberty Ridge site reported a relatively high background concentration (75 $\mu g/m^3$). During October 21, a large high pressure system was centered over the southeastern states, causing the persistent southwesterly winds at Clifty Creek. The same synoptic situation prevailed on the following day which was the day of the third highest 24-hour SO_2 concentration, also observed at the Bacon Ridge site. The calculated concentration isopleths for this day show that either version of CRSTER could have given the observed 24-hour concentration if more representative wind data had been used for model input. The calculated 24-hour concentration peak appears to be shifted counter-clockwise from the observed peak.

5. Highest 3-Hour Concentration at Clifty Creek in 1976—October 28, hours 14-16.

During the afternoon of October 28, high hourly SO_2 concentrations were reported at Canip Creek (99 degrees, 8.0km), Rykers Ridge (56 degrees, 7.4km) and Liberty Ridge (174 degrees, 3.1km) under conditions of light variable winds. During this period a large high pressure system, centered over the lower Ohio Valley, controlled the weather throughout the entire U.S. There appears to have been a wide arc of high concentrations from northeast to south of the plant. During hour 14, concentrations of 1582, 542, and 569 $\mu g/m^3$ were observed at Canip Creek, Rykers Ridge and Liberty Ridge respectively. While a steady state sequential gaussian model could have a simulated these high concentrations at any one of the sites for either of the reported hourly stabilities (B,C,C), it definitely could not have given all of the values at once. It is of interest to compare isopleths of 3-hour concentrations calculated by both versions of CRSTER. The Turner version gives concentrations over 300 $\mu g/m^3$ NNE of the plant with somewhat lower concentrations to the ENE. The patterns for the CRSTER(Irwin) calculated concentrations is just the opposite. The result is due to the fact that during the first hour of the episode the wind blows toward the NNE with stability class B while the wind for the remaining two hours blows generally toward the ENE with stability class C. The episode analysis presented in Section VI showed that most of the CRSTER(Turner) calculated 3-hour episodes at Clifty Creek occurred with a peak concentration hour stability class of A or B while the CRSTER(Irwin) episodes occurred with peak hour stability class C.

6. Second Highest 3-Hour Concentration at Clifty Creek in 1976 — May 9, hours 15-17.

The weather pattern on this day was similar to the one for October 28, except that the winds reported at Clifty Creek, while variable in direction, were somewhat stronger. During this period high hourly concentrations were observed in a 40 degree arc from North Madison to Rykers Ridge. The highest observed 3-hour concentration was 739 $\mu g/m^3$ at Rykers Ridge. The spatial distribution of calculated high concentrations for this period is narrower than the observed distribution. The peak 3-hour concentration calculated with CRSTER(Turner) was 552 $\mu g/m^3$ while the CRSTER(Irwin) peak value was 1063 $\mu g/m^3$.

7. Highest 24-Hour Concentration at Clifty Creek in 1976 — November 25.

The Hebron Church monitor (24 degrees, 11.6 km) reported elevated SO_2 concentrations for almost the entire day. Winds during this day were moderate and persistent from the SSW. The stability class of the day was netural (D). The synoptic pattern was similar to October 21, 1975, with a high centered over the southeastern states. The background concentration on November 25, 1976 was, however, somewhat lower. Considering the measured background concentrations on this day the concentration isopleths calculated by either version of CRSTER are not inconsistent with the measured 24-hour concentration at Hebron Church. The maximum 24-hour concentration calculated by the Irwin version is, however, a factor of 2 higher that the maximum calculated by the Turner version.

8. Second Highest 24-Hour Concentration at Clifty Creek in 1976 — October 12.

At 10 a.m. on October 12, there was a sharp rise in hourly SO_2 concentrations at each site in the Clifty Creek network. This event coincided with a change in stability class from E to C and a shift in wind direction from SSE to SSW. The rise in background concentration at Liberty Ridge and Canip Creek could be the result of regional SO_2 being trapped aloft during night-time stable conditions and then brought to the ground as the atmosphere became more unstable during the afternoon. Again there is the phenomenon of elevated SO_2 concentrations being observed over a 40 degree sector during the same hour. The pattern of 24-hour concentrations predicted by both versions of CRSTER is shifted well counterclockwise of the observed pattern which gives the highest concentration at Bacon Ridge.

9. Highest 3-Hour Concentration at Tanners Creek in 1975 — October 3, hours 12-14.

   On this day high pressure was centered over the Ohio Valley. During this period of light variable winds, high concentrations were observed from southwest to northeast of the plant. Neither version of CRSTER is able to account for the magnitude or spatial distribution of concentrations during this time.

10. Second Highest 3-Hour Concentration at Tanners Creek in 1975 —October 3, hours 15-17.

    Concentrations during this period are similar to those for the previous three hours except that concentrations at Elizabethtown and Kilby Road are higher. Again the models fail to explain these high concentrations or their spatial distribution, due in large measure to their assumption of steady state conditions for a particular hour.

11. Highest 24-Hour Concentration at Tanners Creek in 1975— April 18.

    Both versions of CRSTER, particularly the Turner version, underpredict the 24-hour concentrations on this day. This might be due

to stack tip or building downwash for the 3 low stacks at Tanners Creek.

12. Second Highest 24-Hour Concentration at Tanners Creek in 1975— January 24.

This episode is similar to April 18 except that the wind is a bit lighter and the atmosphere more unstable. The high background concentrations on this day were similar to those observed at Clifty Creek on January 24. Both versions of the model underpredict concentrations at Lawrenceburg on this day.

13. Highest 3-Hour Concentration at Tanners Creek in 1976— November 26, hours 2-4.

High wind speed, neutral stability impact at Lawrenceburg. The CRSTER (Irwin) underprediction at Lawrenceburg is not as great as for as the previous Tanners Creek episodes.

14. Second Highest 3-Hour Concentration at Tanners Creek in 1976— November 25, hours 22-24.

Situation almost identical to case #13.

15. Highest 24-Hour Concentration at Tanners Creek in 1976— November 25

On this day the highest 1-hour concentrations were observed at Lawrenceburg in the afternoon as the wind increases from 3 to about 6 m/s. Both versions of CRSTER underpredict the 24-hour concentration at Lawrenceburg.

16. Second Highest 24-Hour Concentration at Tanners Creek in 1976— November 26.

The high wind speeds of the previous day continue until afternoon

with high morning SO_2 concentrations reported at Lawrenceburg. While the Turner version of CRSTER gives essentially zero 24-hour concentration at Lawrenceburg, the CRSTER (Irwin) prediction is only low by a factor of 2.

17. Highest 3-Hour Concentration at Muskingum in 1975— October 3, hours 13-15.

On October 3, a large high pressure area was centered over the Ohio Valley. Just before noon, the plume was brought to the ground at the Hackney (40 degrees, 4.3 km), Rich Valley (35 degrees, 8.0 km) and Caldwell (35 degrees, 19.8 km) sites, located along a line to the northeast of the plant. High concentrations were reported until about 5 p.m. The 3-hour concentration is highest for the closest site, Hackney, with considerably lower values reported at the two sites farther from the plant. The on-site ground wind measurements for this day give no indication of plume transport since the winds were nearly calm.

18. Second Highest 3-Hour Concentration at Muskingum in 1975— November 28 hours 14-16.

Again, a high pressure area is centered over the upper Ohio Valley on this day giving light variable winds. During this period high concentrations were observed at Rich Valley for each of the 3 hours even though the winds were quite variable. It appears that either some of the SO_2 is carried over from one hour to the next or that the hourly average plume spread is greater than that assumed by either version of CRSTER.

19. Highest 24-Hour Concentration at Muskingum in 1975— January 28.

On this day a stationary front lies across Ohio. Winds are quite light and the sky is overcast, leading to a neutral stability class assignment for the entire day. The highest 24-hour concentration on this day is measured at Caldwell, the receptor most distant from the plant. The highest hourly concentrations at this receptor occur at midday with the wind, as measured at the 10 meter level, actually blowing toward the plant.

20. Second Highest 24-Hour Concentration at Muskingum in 1975— October 3

This high 24-hour concentration observed at Hackney is due to the midday impact responsible for the high 3-hour concentration measured on this same day. The highest hourly concentrations at Hackney occur during a period of A and B Stability.

21. Highest 3-Hour Concentration at Muskingum in 1976— September 12, hours 11-13.

Winds at Muskingum were light and variable under the influence of high pressure centered over the region. On this day the Beverly monitor (139 degrees, 5.3 km) records the highest 3-hour concentration, with very low values reported at the other sites. Although 3 of the 4 monitors at Muskingum were placed to the northeast of the plant to record impacts associated with prevailing winds, it is obvious that more light wind impacts would be reported with a more symmetric deployment of monitors.

22. Second Highest 3-Hour Concentrations at Muskingum in 1976—June 17 hours 12-14.

Once again a high pressure area is centered over Muskingum and winds are light at midday. During this episode the 3-hour concentration at the closest monitor, Hackney, is a factor of two greater than the value reported at Rich Valley.

23. Highest 24-Hour Concentration at Muskingum in 1976—June 17 (same day as the second highest 3-hour concentration).

After the sharp rise in hourly SO_2 concentrations observed at Hackney and Rich Valley during the late morning and afternoon, the concentrations drop but do not return to the observed very low morning values. The peak 1-hour concentration at Rich Valley occurs at the same time as the higher peak at Hackney. The concentration peak at Caldwell occurs several hours later and represents a much more gradual rise (see Figure VII-3).

24. Second Highest 24-Hour Concentration at Muskingum in 1976 — February 24

Moderate to strong southwest winds occurred at Muskingum in response to a high pressure system centered over the southeastern U.S. The highest hourly concentrations on this day at Hackney, Rich Valley and Caldwell were restricted to the time period 9 a.m.- 6 p.m., which coincides exactly with the period of neutral stability. The lowest 24-hour concentration for the 3 upwind sites occurred at Hackney with the highest value at Rich Valley. The concentration at Caldwell is slightly higher than the Hackney value.

25. Highest 3-Hour Concentration at Gavin in 1975—November 16, hours 14-16.

On this day high pressure was centered just to the south of Gavin, resulting in light to moderate southwest winds over the network.

High 3-hour concentrations were observed at Lakin, Mason, Five Points and Coolville, all sites located along a line to the northeast of the Gavin and Kyger Creek Plants. Although the highest concentration was reported at Mason (789 μg/m^3), the values at the other downwind monitors were only slightly less. One might have expected the concentration at Five Points and Coolville to be lower for stabilities C and D. The fact that those two sites are about 200 feet higher than the closer monitors might compensate for the increased plume dilution at greater distances.

26. Second Highest 3-Hour Concentration at Gavin in 1975-- August 8, hours 10-12.

During this episode, high pressure was centered just to the north of Gavin so that winds were from the east-northeast. The Kerr monitor located about 12 km to the west southwest of the Gavin and Kyger Creek plants reported high concentrations for each of the 3 hours. Concentrations at the other sites were quite low except at New Haven which showed a slight impact due to emissions from the Sporn plant.

27. Highest 24-Hour Concentrations at Gavin in 1975-- November 23

On November 23 a weak high pressure ridge extended from New England to Texas. The winds measured at the Gavin Mount Alto site were quite light from the north to northeast, at least near the ground surface. The high concentrations in the afternoon and night at the Coolville and Wolfpen sites are difficult to explain based upon the winds and assigned stabilities for this period. Relatively high late night concentrations were observed at all sites except Henderson, Lakin, Mason, and Dorcas. These 4 sites have elevations below 800 ft while the others are higher. There appears to have been a layer of high SO_2 concentration covering most of the network. Whether these concentrations are due to emissions from Gavin-Kyger-Sporn or a more distant source or group of sources cannot be determined from the data on hand.

28. Second Highest 24-Hour Concentration at Gavin in 1975— August 8

See discussion for case #26

29. Highest 3-Hour Concentration at Gavin in 1976—March 28, hours 15-17.

This case is almost identical to the August 8, 1975 3-hour episode.

30. Second Highest 3-Hour Concentration at Gavin in 1976—June 17, hours 15-17.

Same story again at Kerr. There definitely needs to be more monitors to the southwest of Gavin.

31. Highest 24-Hour Concentration at Gavin in 1976— April 13.

During the middle part of April 1976, high pressure became established over the eastern U.S. with a north-south stationary front extending from Hudson Bay to northern Mexico. Many high temperature records were set along the east coast during this period at the same time that heavy thunderstorm rains with flooding took place in Texas. This was also a period of relatively high sulfate and ozone concentrations over the eastern U.S. On April 13 the high was centered directly over the Gavin area with light variable winds observed throughout the day. The highest concentrations on this day were reported at Lakin, Mason, Wolfpen, Five Points, New Haven and Dorcas, all sites to the north and east of the Gavin and Kyger plants. The high afternoon and evening concentrations at Dorcas appear to be due to emissions from Sporn. A sequential gaussian model would have problems simulating the spatial and temporal distribution of concentrations on this day as the entire area fills up with SO_2. The timing of the highest hourly concentrations at Lakin, Mason and Five Points does, however, indicate the presence of a well defined plume from the Gavin plant coincident with a line joining these 3 monitoring sites. A more realistic model might allow a more gradual variation of concentration with time.

32. Second Highest 24-Hour Concentration at Gavin in 1976—April 14
The high concentrations from the previous day carry over until late afternoon.

Two types of meteorological conditions appear to be important in the occurrence of the highest and second highest concentrations at the 4 AEP monitoring networks. The first type of episode is associated with persistent SW or SSW winds on the backside of a high pressure system or in advance of an approaching cold front from the west. The other critical meteorological condition is the presence of a high pressure system, often centered over the power plant in question so that the sky is cloudless and the winds light and variable. The light wind and abundant sunshine allow the atmosphere to become unstable at midday leading to high short term concentration impacts as the plume is brought to the ground. This light wind condition is most important for the 3-hour averaging time while the persistent wind case is generally responsible for the worst 24-hour episodes.

The gaussian plume model seems to be most appropriate for the treatment of the persistent wind neutral stability condition. The observed hourly concentrations during the persistent wind condition do not seem as sensitive to changes in stability class as would be expected from the model results. Another problem is that the observed variation of concentration with downwind distance does not always fit the general pattern predicted by the gaussian model. This problem might be due in part to the discrete nature of the assigned stability class. A realistic estimate of a continuous stability parameter, however, would require an on site measurement of the bulk Richardson number.

The sequential gaussian modeling approach has much more difficulty with the light wind unstable condition, which is not consistent with the steady state assumption in the model. During these periods, high concentrations are observed for a given hour over a much wider arc than is predicted by a plume model. The highest concentrations for an hour are generally found within a narrow sector comparable to the calculated angular plume spread. The difficulty arises because the model does not allow a gradual transition of the plume centerline from one hour to the next. It might be feasible to calculate a 3-hour concentration by assuming the plume to be uniformly mixed throughout a sector volume bounded on the top by the mixing height. The development of such a model or a more detailed approach would require the analysis of more light wind episodes. Also, the assumption that the plume is able to penetrate the mixing height, even during these strong subsidence inversions, needs to be re-examined. Plume trapping might have been important in the occurrence of the two day SO_2 episode at Gavin in April 1976. This trapping of the plume, below the elevation it would have otherwise attained under neutral or unstable conditions, could explain the uniformly high hourly SO_2 concentrations downwind of the source during these episode periods.

In addition to the errors that seem to be caused by the steady state assumptions used by the gaussian plume algorithms, other errors are introduced by specific algorithms within the model. For example, when the plume rise algorithm predicts effective plume heights above the effective mixing height the model assumes that there can be no plume impact. This can introduce errors. The second-highest three hour observed concentration occurred during those conditions, consequently neither model predicted any impact. Obviously there is an error in one of the following, the plume rise formula, the plume penetration assumption, the mixing height algorithm, or maybe even the assumption of no impact. Other auxiliary algorithms that may cause errors include the stability class assignment routine, the wind speed profile equation and the emission rate calculations.

As stated earlier in this section, the top few 3-hour and 24-hour concentrations for a year stand apart from the other high concentrations in terms of their magnitude. These episodes are characterized by either of the two meteorological conditions just discussed. As one moves down further into the frequency distribution, however, this pattern becomes less clear. In the case of a subsidence inversion, one reason for this effect is the deployment of the networks primarily to the northeast of the plant along the prevailing wind direction, leaving only one or two sites to monitor background concentrations. In one case at Muskingum and two at Gavin, a 3-hour episode would have been missed were it not for observations at a "background" monitor. These 4 AEP networks are less likely to miss a persistent wind episode since the dominant wind direction for persistence is from the SW or SSW. The networks will, however, miss those more infrequent episodes associated with persistent winds from the north, northwest or west which occur following the passage of a cold front. Another reason for the breakdown of this episode characterization is that a potential episode may not in fact occur because the emissions were too low or the plant was actually shut down, or a "non episode" was promoted to the top 25 group because emissions were extraordinarily high.

In spite of this bias in network site deployment and the variability and uncertainty in the emissons, there is reason to believe that the persistent wind and light wind subsidence inversion conditions are important factors in the occurrence of the highest and second highest 3-hour and 24-hour concentrations at the AEP power plants studied. In the case of the light wind impacts, high pressure can be centered over the area for an extended period, leading to multiday episodes similar to the one which occurred during October 1976 at Clifty Creek and November 1975 at Gavin. The influence of these synoptic features can extend over more than one network as shown by the joint occurrence of episodes.

As the gaussian models are currently applied in support of regulatory analyses, hourly meteorological data is used to provide a statistical variation of meteorological input parameters for the model. The use of actual meteorological data does provide a more self consistent set of inputs than would be possible with a simple random variation of individual parameters. With this emphasis upon the sequential hourly calculation of concentrations, however, the significance of the synoptic patterns is lost. A more reasonable approach would be to identify from available monitoring data those meteorological conditions associated with high 3-hour and 24-hour SO_2 concentrations and then select or develop a model designed to deal with transport and diffusion under these conditions.

VIII. SUMMARY AND CONCLUSIONS

This section presents the major conclusions of the study based upon a review of the numerous analysis results described in the three previous sections. The primary objective of the study was to evaluate and compare two versions of the EPA CRSTER model. In addition, two subordinate objectives were to (1) quantitatively determine the performance of CRSTER through various statistical measures which define the degree of the model error and skill and (2) diagnose and characterize conditions associated with poor model performance. Three approaches were used to achieve these objectives. Statistical summaries of model performance (Chapter V), comparison of the characteristics of the observed and calculated 3-hour and 24-hour episodes (Chapter VI), and an analysis of selected individual episodes (Chapter VII).

An important aspect of this study was to assess the usefulness of the three approaches to evaluate models. Generally, it is concluded that the results of the statistical summaries proved to be of greatest use in assessing model performance, primarily since many of these measures are of significant interest from a regulatory point of view. Of particular interest are performance comparisons that focus on the model's general ability to reproduce peak concentrations, such as highest and second-highest concentrations. Three specific summary statistics that proved useful for this type of analysis were the ratio of the highest observed and predicted concentrations, the average difference (residual) of the highest five percent of predictions and observations, and the average absolute difference of the highest five percent of predictions and observations. Also comparisons of frequency distributions of observed and estimated concentrations were found to be useful since model performance at the upper end of the concentration distribution could be easily evaluated.

As indicated above, one subordinate objective of this study was to diagnose probable causes of poor model performance. While the analyses of observed and calculated episodes revealed interesting features about meteorological conditions associated with peak concentrations, these analyses were of limited value in pointing out causes of poor model performance.

As a result of these analyses, the following general conclusions emerged regarding the performance of the two models.

1. Overall, there was no appreciable difference in performance between the Turner and Irwin versions of CRSTER. Minor differences between the two models were apparent for certain stability categories but these differences were judged insignificant when contrasted with variations seen in measured concentrations.

2. The CRSTER Model showed no systematic bias in estimating maximum gound-level concentrations. Both versions of CRSTER predicted maximum concentrations within a factor of two of the observed values at all sites, for both 3-hour and 24-hour averaging times. Ratios of estimated to observed maximum concentrations ranged between 0.8 and 1.2 for most stations and averaging times.

3. Frequency distributions of estimated 3-hour and 24-hour concentrations reasonably reproduced the frequency distribution of observed concentrations, for three of the four plants. Differences between estimated and observed concentrations above the 90th percentile ranged typically from 10 to 40 percent.

4. Neither version of CRSTER adequately described the locations of observed episodes nor does either adequately describe the meteorological conditions under which episodes occur except those with strong wind conditions. Correlation coefficients between observed and estimated concentrations were generally less than 0.4 at each of the six monitoring stations for Clifty Creek.

5. The models performed poorly during periods involving light winds. Specifically, high concentrations were observed over a large range of directions not shown by the models. This difference is potentially serious when two or more plants impact a site under those conditions.

6. Each model showed skill in estimating concentrations as compared to a simple model using only background as an estimate of hourly values. However, for some performance measures the skill of the model relative to background was marginal.

In summary, the performance of both models was essentially the same. They estimated maximum concentrations with an accuracy that is within the widely accepted "factor of two" and frequently exhibited a much better accuracy. However, they demonstrated poor ability to reliably reproduce observed concentrations for specific events. There do not appear to be any clear-cut reasons to select one model over the other as the better performer.

The conclusions of this study are limited in their scope by the range of network locations and source-receptor configurations which were analyzed. Analysis of data from additional networks will allow the evaluation of point source models for a wider range of source configurations and meteorological conditions.

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Appendix A

Statistical Evaluation of Model Performance

Appendix A

Statistical Evaluation of Model Performance

A. Introduction

This appendix deals with the general issue of model evaluation, discusses specific statistical performance measures, and lists the comprehensive statistical results comparing predicted and observed concentrations at the Clifty Creek Generating Station in 1975. In general, evaluation of dispersion models is a relatively recent concern; although various models have been in common use for a decade or more, limitations of ambient data availability and emissions inventory adequacy have minimized evaluation efforts. More recently, as the numbers and types of models have multiplied, and their use has become more and more critical in major economic and environmental decisions, evaluation of their adequacy has become an important concern. In particular, emphasis has been increasingly placed on evaluation techniques that permit quantitative comparisons of modeled vs. measured concentrations.

B. The Logic of Model Evaluation

There are several aspects of model development, use, and evaluation that need to be defined and discussed in advance of more specific evaluation work. One of the reasons why model evaluation, and quantitative statistical evaluation in particular, has not developed earlier, is that the objectives of modeling have generally not been thought through clearly and precisely enough. The developers of the early models set out to mimic the natural dispersion processes mathematically; there were more than enough needs to justify the effort, and it is doubtful if any detailed thought was, or could have been, given to the multiplicity of possible future uses. However, when quantitative evaluations and comparisons of competing models are needed, it becomes necessary to define the goals very precisely. The following discussion is a brief, far from exhaustive, overview of some of the definitional issues involved in statistical model evaluation.

At the outset of the model evaluation, one must decide precisely what part of the model is to be evaluated--the core algorithm, some larger more integrated algorithm, or the entire computer program.

> Core Algorithm. At the core of most dispersion models is a particular algorithm-- Gaussian steady-state equation, for example, or one of the more intricate trajectory schemes. Included are the various constants used in the algorithm, such as dispersion coefficients or rate constants, and various subordinate algorithms, such as the plume rise calculation.
>
> Total algorithm. For most applications, the total model prediction is based upon multiple applications of the core algorithm, combined in some fashion; e.g. the summation of multiple source contributions, or the combination of sequential hourly predictions to estimate concentrations for longer averaging times. There may easily be features in the process of combination that adversely influence the prediction of the total algorithm, quite apart from the prediction capability of the core algorithm itself.
>
> Program design. In most cases, a model will be implemented by computer, and is quite possible to have the same total algorithm implemented by different computer programs. The designs and the coding of the various programs will differ, probably in an attempt to lower the operating cost. Though these models are surely intended to be algebraically equivalent, it may be necessary in some circumstances to evaluate that equivalence.

The present application includes evaluation of the first two of the three components above. The "Turner" and "Irwin" versions of the model differ essentially in the core algorithm, utilizing different methods of quantifying the dispersion parameters and wind profile coefficients. Hence the comparison of the two is a comparison of these parameterizations, regardless of any other features of the models. In comparing the model predictions with measured ambient values, however, the evaluation necessarily includes the total algorithm, including not only the core algorithm, but also the assumption of steady state conditions for an hour.

The second step in the model evaluation is to define the objective of the modeling itself. This is distinct from the user's purpose in evaluation, that is, whether the evaluation is for the purpose of understanding and improving the model, for the purpose of quantifying the model's performance, or for the purpose of comparing its "skill" to a baseline. Defining the modeling objective means that the desired predictions or model outputs must be specified precisely,much more precisely than is customarily done, in order to permit the statistical evaluation techniques to apply. The best illustration of what is meant by modeling objectives, and the precision with which they must be specified, is to list some of the more common objectives:

1. Prediction of the concentration at a specified time and specified point in 3-dimensional space.
2. Prediction of the annual mean concentration at a specified point.
3. Prediction of the maximum annual mean concentration in the vicinity, regardless of location.
4. Prediction of the second highest 1- or 3-hour average concentrations at a specific site.

5. Prediction of the second highest 1- or 3-hour average concentrations in the vicinity, regardless of location.
6. Prediction of the proportion of concentrations over a specified threshold at a given location.
7. Prediction of the spatial pattern of annual average concentrations e.g. the ratio, of or difference between, concentrations at specified points.

This list of objectives is of course in no way complete, but hopefully illustrates some of the distinctions that need to be made in order to utilize statistical methods. For instance, the distinction between 2 and 3 and between 4 and 5 is important and often confused.

A third factor that is relevant to model evaluation, already alluded to above, is the users purpose for the evaluation. Javitz and Ruff[25] define as two separate categories techniques for intermediate evaluation and for final evaluation. Although the labels "intermediate" and "final" imply a logical time sequence which is not often realized, there are different purposes for model evaluation, and they do tend to lead to different types of evaluation techniques, athough the two types are by no means distinct. One purpose for evaluation is to understand the model's behavior, to identify how it may fail to describe reality. This may be done simply to better understand the model or the physical processes it represents, or it may be done to identify possible improvements or modifications. This type of evaluation, called "intermediate evaluation" by Javitz and Ruff, leads to the use of exploratory statistical tools such as scatter plots, regression analysis, and the tabulation of prediction errors by meteorological conditions.

The second purpose for model evalution is to provide quantitative measures of model performance for comparative and/or regulatory purposes. This purpose, called "final evaluation" by Javitz and Ruff[25], leads to the use of objective statistical measures of quantitative performance, such as percent misclassification or confidence limits. Because the desire here is for specific, precise numbers representing model performance, the model's objective must be specified in a comparably specific, precise manner. This is not so simple as it may seem; most users desire models that will do all things, and it is difficult to be precise about exactly what constitutes good model performance.

A third user purpose, related to the second, involves the evaluation of model "skill", which is somewhat different from a simple performance quantification. In this case, a model's performance is compared not to that of another dispersion model, but to a baseline reference model for which there is no implied skill. This is a concept borrowed from weather forecasting, where forecasts based on simple concepts like persistence are used as reference models. Since dispersion models are becoming increasingly complex and expensive, some measure of their "skill" compared to simpler approaches would be a desirable goal.

C. Statistics For Model Performance Evaluation

As has just been discussed, model performance can be evaluated in different ways and for different purposes; it must be emphasized that no single set of evaluation statistics can be used to characterize the performance of every model for every purpose. Statistics that are appropriate for the evaluation of photochemical models or urban area-source models may not be appropriate for point source model evaluation. Hayes[24] outlined a conceptual framework for the evaluation of models that included performance measures generally appropriate for the evaluation of models where single-source plumes were not critical. Javitz and Ruff[25] prepared an evaluation system for the RAM Model using the RAPS data base. Both approaches provide valuable insight into model evaluation, but neither had to address in detail the peculiarities of single-source model evaluation. Bowne[26] presented a general discussion on of model validation which suggested specific tests which did address some point source model evaluation problems.

Hayes[24] considered four generic categories of performance measures; peak, station, area and exposure/dosage. The first category includes those measures involving the differences between the predicted and observed concentration peak, its level, location and timing. The second category includes measures based on concentration differences between prediction and observation at specific measurement stations. In the third category are measures based on differences in the concentration field over a specified area, while the fourth category includes measures relating to differences in population exposure and dosage within a specified area.

In this project the peak and station performance categories are important. Any consideration of area and exposure/dosage performance measures is precluded by the importance of the point source plume impact in such situations and the inability to completely specify its location either with the models or by means of the measured data. In addition, the point source peak performance measures concentrate on the peak level only for the same reasons. Therefore, only station performance measures will be considered in detail, as the primary means of statistically comparing the measured and modeled point source impacts. Note that this includes a comparison only of concentrations predicted at the "selected" set of receptors, i.e. those that correspond to the actual monitoring sites. There is no consideration in the statistical evaluation for the "full set" of hypothetical receptor points used in the model.

The systematic bias attribute refers to the tendency for a model to consistently underpredict or overpredict concentrations on a long-term basis. Basically, the attribute is the mean residual between predicted and observed concentrations for a particular averaging time, i.e. over-and underpredictions may cancel each other. Hayes[24] applies this statistic only to the values above a threshold (NAAQS is suggested) and normalizes by the average of the values above the threshold. EPA[27] recommended that all observed-predicted pairs be considered and that calculation of the mean and standard deviation of the differences and the mean and standard deviation of the relative differences (normalized by observed concentration). Bowne[26] recommends that the average and standard deviation of the residuals should be calculated and that the histogram and cumulative distribution function be examined.

For this project the differences or residuals were defined as follows:

$$R = P + B - O \qquad \text{(A-1)}$$

where R = Residual concentration ($\mu g/m^3$)

P = Predicted concentration ($\mu g/m^3$)

B = Background concentration ($\mu g/m^3$)

O = Observed concentration ($\mu g/m^3$)

Residuals were calculated for 1-hour, 3-hour and 24-hour periods at all six monitoring sites in the Clifty Creek network for one year (1975), and are included in Tables A-1 through A-6, along with summaries of other statistics.

The gross error attribute is meant to measure the degree to which a model makes large errors in either direction; it thus reflects the effect of both bias and scatter. This attribute is generally calculated by taking the average absolute value of the residuals between predicted and observed concentrations for a particulate averaging time, i.e. not letting over- and under- predictions cancel. Hayes[24] applies the statistic only to values above a threshold (NAAQS is suggested) and normalizes by the average of the values above the threshold. The average absolute error loss function suggested by Javitz and Ruff[25] is applied to all prediction-observation pairs, but is equivalent otherwise. Bowne[26] also suggested the calculation of the absolute residuals. EPA[27] applied their gross error statistic to all prediction-observation pairs, but suggest calculation of the mean and standard deviation of the absolute differences and absolute relative differences. For this project the gross error statistic was defined as follows:

$$GE = |P+B-O| \qquad (A-2)$$

where

Table A-1. 1-Hour Averages CRSTER (Turner)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PREDICTION*						
Ratio of mean predicted to mean observed						
Data Set A	0.198	0.305	0.259	0.750	0.500	0.320
Data Set B	11.0	4.59	9.68	3.94	5.75	5.86
Data Set C	1.06	1.50	1.23	1.59	1.96	0.938
Largest Ratio Range						
Data Set A	0.673	0.972	0.490	1.60	2.48	0.682
Data Set B	59.8	286.	425.	64.3	25.0	14.5
Data Set C	1.17	1.66	1.40	1.78	2.72	1.16
Smallest Ratio Range						
Data Set A	0.027	0.062	0.133	0.261	0.191	0.179
Data Set B	1.88	9.	5.04	1.60	1.86	1.58
Data Set C	0.978	1.34	0.757	1.37	1.46	0.671
SYSTEMATIC BIAS						
Mean of differences (μg/m^3)	-2.02	-1.35	-3.37	5.20	-4.78	1.31
Standard deviation of differences (μg/m^3)	78.0	71.0	82.9	79.0	37.5	55.1
Mean of relative differences	1.43	0.723	0.581	0.751	0.181	1.35
Standard deviation of relative diff.	8.50	4.73	4.83	4.95	2.20	3.96
GROSS ERROR (units)						
Mean of absolute difference (μg/m^3)	30.7	21.1	24.6	27.7	12.3	19.7
Standard deviation of absolute diff (μg/m^3)	71.7	67.8	79.2	74.1	35.7	51.5
Mean of relative absolute diff.	1.81	0.985	0.945	1.11	0.539	1.55
Stand. dev. of rel. absol. diff.	8.42	4.68	4.78	4.88	2.14	3.89
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.359	0.382	0.313	0.397	0.614	0.367

* Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

Table A-2. 1-Hour Averages CRSTER (Irwin)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PPEDICTION*						
Ratio of mean predicted to mean observed						
Data Set A	0.198	0.304	0.313	0.606	0.555	0.388
Data Set B	7.27	6.94	10.9	4.44	10.9	2.66
Data Set C	1.22	1.49	1.17	1.39	2.82	0.792
Largest Ratio Range						
Data Set A	0.631	0.890	1.25	1.52	2.71	0.685
Data Set B	170.	22.5	39.9	32.0	43.7	5.34
Data Set C	1.28	1.55	1.37	1.53	3.47	1.02
Smallest Ratio Range						
Data Set A	0.027	0.062	0.133	0.261	0.273	0.223
Data Set B	3.06	1.73	2.27	1.52	2.71	1.31
Data Set C	1.16	1.12	0.718	1.13	2.25	0.553
SYSTEMATIC BIAS						
Mean of differences (μg/m^3)	-2.11	1.30	10.6	9.00	-1.92	2.63
Standard deviation of differences (μg/m^3)	77.8	73.6	111.0	88.0	53.8	53.2
Mean of relative differences	1.36	0.859	1.08	0.862	0.326	1.43
Standard deviation of relative diff.	7.49	6.06	9.15	5.97	3.15	4.36
GROSS ERROR						
Mean of absolute difference (μg/m^3)	30.3	22.8	34.1	30.1	14.4	19.4
Standard deviation of absolute diff (μg/m^3)	71.7	70.0	106.0	83.1	51.9	49.6
Mean of relative absolute diff.	1.74	1.11	1.40	1.21	0.670	1.61
Stand. dev. of rel. absol. diff.	7.41	6.02	9.10	5.91	3.10	4.29
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.369	0.406	0.323	0.402	0.469	0.417

* Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

Table A-3. 3-Hour Averages - CRSTER (Turner)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PREDICTION* Ratio of mean predicted to mean observed						
Data Set A	0.150	0.499	0.299	0.361	0.617	0.239
Data Set B	5.66	7.13	5.29	2.49	5.78	2.27
Data Set C	0.934	1.34	1.04	1.25	1.26	0.638
Largest Ratio Range						
Data Set A	0.395	1.31	0.497	0.848	2.44	0.502
Data Set B	91.8	44.1	17.4	7.35	63.6	3.53
Data Set C	1.02	1.37	1.29	1.48	2.02	1.01
Smallest Ratio Range						
Data Set A	0.017	0.232	0.150	0.238	0.182	0.137
Data Set B	1.27	1.31	2.37	1.46	1.62	1.24
Data Set C	0.883	1.23	0.803	1.15	0.858	0.415
SYSTEMATIC BIAS						
Mean of differences($\mu g/m^3$)	-1.89	-1.36	-3.41	5.08	-4.82	1.32
Standard deviation of differences($\mu g/m^3$)	59.6	50.0	59.6	76.3	26.2	42.2
Mean of relative differences	1.17	0.543	0.432	0.637	0.0851	1.12
Standard deviation of relative diff.	5.63	2.98	3.03	4.58	1.40	3.09
GROSS ERROR						
Mean of absolute difference (ug/m^3)	27.5	18.0	21.8	26.9	11.2	17.8
Standard deviation of absolute diff.(ug/m^3)	52.9	46.7	55.5	71.6	24.2	38.3
Mean of relative absolute diff.	1.54	0.798	0.790	0.996	0.443	1.32
Stand. dev. of rel. absol. diff.	5.54	2.92	2.96	4.51	1.34	3.01
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.456	0.520	0.429	0.533	0.730	0.483

*Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

Table A-4. 3-Hour Averages - CRSTER (Irwin)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PREDICTION*						
Ratio of mean predicted to mean observed						
Data Set A	0.155	0.375	0.498	0.406	0.671	0.376
Data Set B	1.67	4.04	4.37	4.07	4.93	3.39
Data Set C	1.05	1.18	1.37	1.44	1.80	0.678
Largest Ratio Range						
Data Set A	0.464	0.618	0.994	0.838	3.07	0.686
Data Set B	3.28	24.7	2.98	11.6	10.8	16.9
Data Set C	1.50	1.29	1.76	1.52	2.54	0.964
Smallest Ratio Range						
Data Set A	0.017	0.243	0.217	0.238	0.225	0.236
Data Set B	1.17	1.87	8.85	1.83	3.07	1.27
Data Set C	0.908	1.11	0.949	1.30	1.51	0.427
SYSTEMATIC BIAS						
Mean of differences (μg/m^3)	-1.98	1.33	10.6	8.68	-2.15	2.61
Standard deviation of differences (μg/m^3)	60.2	51.2	83.6	64.5	36.3	40.4
Mean of relative differences	1.10	0.649	0.792	0.665	0.209	1.18
Standard deviation of relative diff.	4.86	3.57	4.62	3.62	1.99	3.29
GROSS ERROR						
Mean of absolute difference (μg/m^3)	27.2	19.3	30.3	25.9	12.9	17.4
Standard deviation of absolute diff (μg/m^3)	53.7	47.5	78.6	59.7	34.0	36.6
Mean of relative absolute diff.	1.46	0.890	1.09	0.981	0.547	1.36
Stand. dev. of rel. absol. diff.	4.77	3.52	4.56	3.55	1.93	3.22
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.459	0.545	0.425	0.511	0.613	0.535

*Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

Table A-5. 24-Hour Averages CRSTER (Turner)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PREDICTION*						
Ratio of mean predicted to mean observed						
Data Set A	0.478	0.669	0.321	0.750	0.773	0.328
Data Set B	2.51	2.48	1.68	1.28	1.05	1.88
Data Set C	0.795	0.899	0.755	1.08	0.875	0.765
Largest Ratio Range						
Data Set A	0.907	1.25	0.741	1.14	0.908	0.928
Data Set B	8.01	7.22	1.74	2.62	1.67	2.95
Data Set C	0.967	1.07	0.988	1.36	0.910	0.844
Smallest Ratio Range						
Data Set A	0.251	0.395	0.107	0.364	0.679	0.157
Data Set B	0.937	0.761	1.68	0.887	0.745	0.928
Data Set C	0.729	0.839	0.542	1.09	0.768	0.555
SYSTEMATIC BIAS						
Mean of differences ($\mu g/m^3$)	-1.89	-1.36	-3.41	5.08	-4.82	1.32
Standard deviation of differences ($\mu g/m^3$)	59.6	50.0	59.6	76.3	26.2	42.2
Mean of relative differences	0.704	0.248	0.184	0.364	-0.0824	0.389
Standard deviation of relative diff.	2.83	1.21	1.11	1.12	0.453	0.961
GROSS ERROR						
Mean of absolute difference ($\mu g/m^3$)	20.7	12.3	16.3	14.3	8.10	12.7
Standard deviation of absolute diff. ($\mu g/m^3$)	25.2	16.5	23.8	19.4	9.00	15.2
Mean of relative absolute diff.	1.04	0.491	0.513	0.559	0.258	0.606
Stand. dev. of rel. absol. diff.	2.72	1.14	1.00	1.04	0.381	0.841
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.558	0.710	0.567	0.716	0.887	0.568

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*Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

Table A-6. 24-Hour Averages - CRSTER (Irwin)

MODEL PERFORMANCE STATISTICS - CLIFTY CREEK

1975 - BACKGROUND INCLUDED

Statistic	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
MODEL PEAK PREDICTION*						
Ratio of mean predicted to mean observed						
Data Set A	0.535	0.689	0.554	0.931	0.780	0.493
Data Set B	0.180	1.92	3.65	2.76	1.28	1.72
Data Set C	0.830	1.09	1.53	1.72	0.892	0.784
Largest Ratio Range						
Data Set A	0.981	0.963	1.22	2.19	0.908	0.928
Data Set B	2.18	6.88	5.58	4.45	2.23	2.98
Data Set C	0.917	1.20	1.63	2.32	1.09	0.922
Smallest Ratio Range						
Data Set A	0.252	0.479	0.327	0.364	0.679	0.157
Data Set B	1.02	0.960	2.53	1.44	0.775	0.928
Data Set C	0.887	1.03	1.40	1.57	0.894	0.565
SYSTEMATIC BIAS						
Mean of differences (μg/m³)	-1.98	1.33	10.6	8.68	-2.15	2.61
Standard deviation of differences (μg/m³)	60.2	51.2	83.6	64.5	36.3	40.4
Mean of relative differences	0.616	0.327	0.503	0.387	0.0248	0.434
Standard deviation of relative diff.	2.38	1.25	1.48	1.01	0.784	0.988
GROSS ERROR						
Mean of absolute difference (μg/m³)	20.1	12.8	23.4	16.6	8.89	12.2
Standard deviation of absolute diff. (μg/m³)	23.7	18.1	38.9	28.2	12.3	13.8
Mean of relative absolute diff.	0.954	0.532	0.723	0.576	0.319	0.613
Stand. dev. of rel. absol. diff.	2.27	1.17	1.39	0.916	0.717	0.888
TEMPORAL ALIGNMENT						
Pearson correlation coefficient	0.604	0.690	0.498	0.682	0.801	0.641

*Data Set A: Five highest observed concentrations and the predicted concentrations during those peak observations
Data Set B: Five highest predicted concentrations and the observed concentrations during those peak predictions
Data Set C: Five highest observed and predicted concentrations during the year regardless of when they occurred.

GE = Gross error residual

The means and standard deviation for all the gross error residuals and the relative gross error residuals (Equation A-2 divided by the observed value) are presented in Tables A-1 through A-6.

Tables A-7 through A-9 present summaries of the systematic bias and gross error statistics similar to Tables A-1 through A-6, except that only time periods exceeding a threshold are included, in the manner suggested by Hayes[24]. The threshold used was 128 $\mu g/m^3$, which is the 95th percentile of the observed distribution.

The peak prediction attribute is a peak performance measure. The attribute estimates the model's ability to correctly predict the peak concentration level, timing and location. Hayes[24] recommends a simple ratio calculation between the peak predicted concentration and the peak measured concentration. It is also recommended that the difference in the timing of the station peak should be included. However, the timing of the peak, as well as the prediction of peak location, are so difficult for a plume model to predict in the vicinity of a point source that we have not included those statistics. We recommend that they not be considered meaningful for point-source plume models unless extremely extensive ambient monitoring data are available.

The peak prediction attribute calculated for this model evaluation used statistics recommended in a draft EPA[27] report. Although essentially the same ratio suggested by Hayes[24], a more complicated procedure which involves sorting, geometric means and the range of ratios between the predicted and observed calculations was used. The five highest observed concentrations and the predicted concen-

Table A-7

One Hour Systematic Bias and Gross Error Statistics for Values Above the 95th Percentile--Clifty Creek 1975

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Camp Creek
CRSTER (Turner)						
SYSTEMATIC BIAS ATTRIBUTE						
Mean of Differences (μg/m^3)	-37.7	-28.5	-26.4	33.1	-39.0	-98.0
Standard Deviation of Differences (μg/m^3)	252.	283.	314.	272.	181.	238.
Mean of Relative Differences	5.88	3.69	3.05	4.44	0.229	1.25
Standard Deviation of Relative Differences	25.9	16.6	16.9	15.9	3.07	10.4
GROSS ERROR ATTRIBUTE						
Mean of Absolute Difference (μg/m^3)	203.	203.	212.	206.	104.	191.
Standard Deviation of Absolute Difference (μg/m^3)	153.	200.	233.	180.	153.	174.
Mean of Relative Absolute Difference	6.78	4.53	3.97	5.11	0.949	2.38
Standard Deviation of Relative Absolute Difference	25.7	16.4	16.7	15.7	2.93	10.2
CRSTER (Irwin)						
SYSTEMATIC BIAS ATTRIBUTE						
Mean of Differences (μg/m^3)	-41.4	12.3	118.	75.9	25.9	-72.9
Standard Deviation of Differences (μg/m^3)	252.	285.	347.	291.	262.	229.
Mean of Relative Differences	4.60	5.41	6.99	5.41	3.21	2.53
Standard Deviation of Relative Differences	21.8	21.6	29.0	19.1	11.3	12.9
GROSS ERROR ATTRIBUTE						
Mean of Absolute Differences (μg/m^3)	201.	216.	264.	227.	144.	175.
Standard Deviation of Absolute Difference (μg/m^3)	158.	186.	254.	198.	220.	165.
Mean of Relative Absolute Difference	5.51	6.15	7.54	5.99	3.81	3.49
Standard Deviation of Relative Absolute Difference	21.6	21.4	28.9	19.0	11.1	12.7

Table A-8

Three Hour Systematic Bias and Gross Error Statistics for Values Above the 95th Percentile--Clifty Creek 1975.

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
CRSTER (Turner)						
SYSTEMATIC BIAS ATTRIBUTE Mean of Differences ($\mu g/m^3$)	-34.4	-21.3	-14.9	26.2	-27.5	-82.6
Standard Deviation of Differences ($\mu g/m^3$)	178.	186.	216.	176.	120.	172.
Mean of Relative Differences	3.45	1.73	2.11	2.52	0.166	0.572
Standard Deviation of Relative Differences	14.4	8.20	9.51	7.55	1.89	4.49
GROSS ERROR ATTRIBUTE Mean of Absolute Difference ($\mu g/m^3$)	151.	143.	164.	142.	83.2	148.
Standard Deviation of Absolute Difference ($\mu g/m^3$)	99.0	121.	141.	107.	91.2	120.
Mean of Relative Absolute Difference	4.22	2.46	2.90	3.03	0.765	1.59
Standard Deviation of Relative Absolute Difference	14.2	8.01	9.30	7.36	1.73	4.23
CRSTER (Irwin)						
SYSTEMATIC BIAS ATTRIBUTE Mean of Differences ($\mu g/m^3$)	-37.4	12.0	105.	64.2	27.7	-77.8
Standard Deviation of Differences ($\mu g/m^3$)	181.	181.	239.	195.	173.	163.
Mean of Relative Differences	2.65	2.86	4.17	3.23	1.99	0.611
Standard Deviation of Relative Differences	11.6	10.7	13.0	10.3	5.86	5.79
GROSS ERROR ATTRIBUTE Mean of Absolute Differences ($\mu g/m^3$)	151.	144.	200.	160.	117.	134.
Standard Deviation of Absolute Difference ($\mu g/m^3$)	107.	110.	167.	129.	131.	121.
Mean of Relative Absolute Difference	3.44	3.44	4.58	3.66	2.47	1.52
Standard Deviation of Relative Absolute Difference	11.3	10.5	12.9	10.2	5.67	5.62

Table A-9

24 Hour Systematic Bias and Gross Error Statistics for Values Above the 95th Percentile--Clifty Creek 1975

	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
CRSTER (Turner)						
SYSTEMATIC BIAS ATTRIBUTE						
Mean of Differences ($\mu g/m^3$)	-36.7	-9.53	-51.8	0.746	-19.6	-59.4
Standard Deviation of Differences ($\mu g/m^3$)	71.4	52.6	64.1	61.2	26.8	49.3
Mean of Relative Differences	0.0693	0.754	-0.355	0.579	-0.130	-0.449
Standard Deviation of Relative Differences	1.56	2.97	0.441	2.64	0.312	0.334
GROSS ERROR ATTRIBUTE						
Mean of Absolute Difference ($\mu g/m^3$)	65.1	40.4	65.2	43.8	29.5	59.4
Standard Deviation of Absolute Difference ($\mu g/m^3$)	46.2	33.8	49.4	41.6	13.0	49.3
Mean of Relative Absolute Difference	0.785	1.16	0.504	0.942	0.278	0.449
Standard Deviation of Relative Absolute Difference	1.34	2.85	0.245	2.53	0.171	0.334
CRSTER (Irwin)						
SYSTEMATIC BIAS ATTRIBUTE						
Mean of Differences ($\mu g/m^3$)	-38.4	1.74	47.8	38.2	-3.48	-50.6
Standard Deviation of Differences ($\mu g/m^3$)	64.7	58.5	105.	90.1	51.7	43.0
Mean of Relative Differences	-0.133	0.505	1.44	0.879	0.117	-0.372
Standard Deviation of Relative Differences	0.847	1.75	2.77	1.93	0.742	0.255
GROSS ERROR ATTRIBUTE						
Mean of Absolute Differences ($\mu g/m^3$)	59.8	42.8	90.9	70.6	40.3	50.6
Standard Deviation of Absolute Difference ($\mu g/m^3$)	44.9	38.7	69.6	66.6	29.7	43.0
Mean of Relative Absolute Difference	0.558	0.849	1.74	1.15	0.482	0.372
Standard Deviation of Relative Absolute Difference	0.644	1.61	2.59	1.77	0.555	0.255

trations during those periods for each averaging time were assembled in Data Set A. (Note that only one one-hour or three-hour average per day was chosen). Data Set B consisted of the top 5 predicted concentrations and observed concentrations for each averaging period. The final Data Set (C) combined the top five observed and top five predicted concentrations. For each data set, the geometric mean and the ratio of predicted to observed geometric means was calculated, and the ratio for each of the top five paired concentrations and the largest and smallest of these ratios was determined. The results for the six sites and all three averaging times are also included in Tables A-1 through A-6.

Javitz and Ruff[25] defined "accuracy scores" as suggested measured for model evaluation. Accuracy scores assess the "loss" due to differences in predicted and observed concentrations, with each accuracy score based on a different specified "loss function". The loss function quantitatively describes the loss, or relative seriousness, associated with any prediction errors. For this project only the following five "objective" loss functions proposed by Javitz and Ruff were calculated. In the descriptions that follow, OC and PC mean observed and predicted concentration, respectively.

(1) Average Absolute Error

$$A = \frac{1}{n} \sum_{i=1}^{n} |OC_i - PC_i| \qquad \text{(A-3)}$$

With this loss function (absolute error), underprediction and overprediction are judged to be equally undesirable. Furthermore, a misprediction of 2 ppm is twice as undesirable as a misprediction of 1 ppm.

(2) Average-Squared Error

$$A = \frac{1}{n} \sum_{i=1}^{n} (OC_i - PC_i)^2 \tag{A-4}$$

With this loss function (squared error) also, underprediction and overprediction are judged to be equally undesirable. A misprediction of 2 ppm is four times as undesirable as a misprediction of 1 ppm. This type of loss function is used in many statistical tests.

(3) Percent Incorrect Predictions with Absolute Error Threshold

$$A = \frac{1}{n} \sum_{i=1}^{n} \begin{cases} 0 & \text{if } \left|OC_i - PC_i\right| \le \epsilon \\ 1 & \text{if } \left|OC_i - PC_i\right| > \epsilon \end{cases} \tag{A-5}$$

With this loss function, only prediction errors that exceed a certain absolute threshold are counted against the prediction model. Underprediction and overprediction are judged to be equally undesirable. Whenever the misprediction exceeds the threshold, its magnitude is ignored. Thus, moderate and huge misprediction errors count equally. (The error threshold must be user supplied).

(4) Percent Incorrect Prediction with Constant percentage Error Threshold (ϵ)

$$A = \frac{1}{n} \sum_{i=1}^{n} \begin{cases} 0 & \text{if } \left|\dfrac{OC_i - PC_i}{OC_i}\right| \le \epsilon \\ 1 & \text{if } \left|\dfrac{OC_i - PC_i}{OC_i}\right| > \epsilon \end{cases} \tag{A-6}$$

This loss function is similar to the preceding, except that the threshold criterion is percentage error. (In practice, the case where OC = 0 is not allowed.)

(5) Symmetric High-Low Loss Function (Cutoff)

$$A = \frac{1}{n} \sum_{i=1}^{n} \begin{cases} 0 & \text{if } \begin{array}{l} PC_i \text{ and } OC_i \le \text{cutoff} \\ \text{or} \\ PC_i \text{ and } OC_i > \text{cutoff} \end{array} \\ 1 & \text{if otherwise} \end{cases} \tag{A-7}$$

This loss function is particularly appropriate when an alert level cutoff exists. Here A is the percentage of false alerts and failures to predict actual pollutant alert levels. The magnitude of the false alert is ignored as is the magnitude of the underprediction when an actual pollutant alert condition is not predicted.

The accuracy scores presented in this report do not have explicit formulas for confidence limits. However, confidence limits for these statistics may be derived. To illustrate the procedure for the accuracy score, let A be an accuracy score computed from a data set. Subdivide the data set into k data subsets. Javitz and Ruff[25] recommend k = 5 as a reasonble value. In this case, the first subset should contain the data from time-periods 1, 6, 11, 16, etc. The second subset should contain data from time-periods 2, 7, 12, 17, etc. In this fashion each subset contains data from every fifth time period. This procedure ensures that the data subsets are comparable with each other and to the full data set, except when the data set has a "periodicity" of five time periods. As an example of such periodicity, consider the case wherein the periods were days and the full data set consisted only of weekdays. Then the five data sets would not be comparable (since one would consist only of Mondays, another only of Tuesdays, etc.). In this case, one should construct six data subsets.

The accuracy scores for each of the subsets can be computed if these accuracy scores are labeled A_1, A_2,....., A_k; then the sample standard deviation of these subset scores is

$$s = \sqrt{\frac{1}{k-1}\sum_{i=1}^{k}(A_i - \bar{A})^2} \qquad \text{(A-8)}$$

where

$$\bar{A} = \frac{1}{k} \sum_{i=1}^{k} A_i \qquad \text{(A-9)}$$

The accuracy-score A computed from the total data set has a smaller standard error than the accuracy scores computed from the smaller data subsets. We may approximate the standard error of A by

$$\frac{S}{\sqrt{k}} \; .$$

Thus a 90-percent confidence interval for the true value of the accuracy score is given by

$$A \pm t_{k-1,.95} \; \frac{S}{\sqrt{k}} \qquad \text{(A-10)}$$

where $t_{k-1,.95}$ is the upper 95-percent cutoff point of the Student's t-distribution with k - 1 (four) degrees of freedom. The thresholds used in this report are listed in the tables. (Tables A-10 to A-12).

Contingency Table Summaries

A contingency table is a convenient way to display a joint frequency distribution, and can be used to develop a simple skill score. For this analysis, the contingency tables show the relationship between observed and predicted plus background concentration (Tables A-13 to A-15). The approximate quartiles of the observed concentrations

Table A-10

Accuracy Scores

Clifty Creek Network 1975

1 Hour Averages Background Included

CRSTER(Turner)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	30.7	21.1	24.6	27.7	12.3	19.7
Confidence Limits	1.32	1.75	0.753	1.18	0.676	0.302
Average Squared Error						
Statistic ($\mu g/m^3$)	6080	5040	6880	6270	1430	3030
Confidence Limits	708	1020	947	944	700	384
Fraction Incorrect Predictions with Absolute Error Threshold						
Threshold = 5 $\mu g/m^3$						
Statistics	0.685	0.508	0.578	0.623	0.483	0.621
Confidence Limits	0.0045	0.0044	0.012	0.011	0.0043	0.0042
Fraction Incorrect Predictions with Constant Percentage Error Threshold						
Threshold = 5%						
Statistics	0.0609	0.0269	0.0233	0.0338	0.0161	0.0632
Confidence Limits	0.0030	0.0016	0.0013	0.0037	0.0029	0.0030
Symmetric High-Low Loss Function						
Cutoff = 250 $\mu g/m^3$						
Statistic	0.0387	0.0243	0.0232	0.0332	0.0058	0.0130
Confidence Limits	0.0037	0.0030	0.0011	0.0021	0.0011	0.0015

CRSTER (Irwin)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	30.3	22.8	34.1	30.1	14.4	19.4
Confidence Limits	1.45	1.17	1.27	1.17	1.17	0.267
Average Squared Error						
Statistic ($\mu g/m^3$)	6060	5420	12400	7820	2900	2840
Confidence Limits	903	368	1090	728	1130	338
Fraction Incorrect Predictions with Absolute Error Threshold						
Threshold = 5 $\mu g/m^3$						
Statistics	0.684	0.509	0.583	0.624	0.487	0.621
Confidence Limits	0.0037	0.0036	0.012	0.011	0.0046	0.0052
Fraction Incorrect Predictions with Constant Perc. Error Threshold						
Threshold = 5%						
Statistic	0.0614	0.0307	0.0430	0.0362	0.0213	0.0658
Confidence Limits	0.0024	0.0014	0.0020	0.0058	0.0033	0.0036
Symmetric High-Low Loss Function						
Cutoff = 250 $\mu g/m^3$						
Statistic	0.0371	0.0279	0.0410	0.0376	0.0080	0.0135
Confidence Limits	0.0029	0.0025	0.0022	0.0029	0.0017	0.0014

Table A-11

Accuracy Scores

Clifty Creek Network 1975

3 Hour Averages Background Included

CRSTER(Turner)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	27.5	18.0	21.8	23.5	11.2	17.8
Confidence Limits	0.40	1.1	0.24	0.54	0.21	0.11
Average Squared Error						
Statistic ($\mu g/m^3$)	3550	2500	3560	3080	712	1780
Confidence Limits	110	340	200	130	120	270
Fraction Incorrect Predictions with Absolute Error Thresholds						
Threshold = 2.6 $\mu g/m^3$						
Statistics	0.826	0.699	0.755	0.794	0.663	0.789
Confidence Limits	0.0057	0.-073	0.013	0.0068	0.0041	0.0027
Fraction Incorrect Predictions with Constant Percentage Error Threshold						
Threshold = 2.6 %						
Statistics	0.103	0.0484	0.0480	0.0595	0.0249	0.125
Confidence Limits	0.0030	0.0018	0.0044	0.0036	0.0021	0.0029
Symmetric High-Low Loss Function						
Cutoff = 73 $\mu g/m^3$						
Statistic	0.126	0.0839	0.102	0.112	0.0632	0.0939
Confidence Limits	0.0050	0.0070	0.0074	0.0079	0.0049	0.0060

CRSTER (Irwin)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	27.2	19.3	30.3	25.9	12.9	17.4
Confidence Limits	0.40	0.80	0.39	0.58	0.39	0.22
Average Squared Error						
Statistic ($\mu g/m^3$)	3630	2630	7100	4240	1320	1640
Confidence Limits	98.	280.	290.	230.	200.	240.
Fraction Incorrect Predictions with Absolute Error Thresholds						
Threshold = 2.6 $\mu g/m^3$						
Statistics	0.824	0.702	0.758	0.797	0.666	0.786
Confidence Limits	0.0047	0.0069	0.0013	0.0063	0.0041	0.0018
Fraction Incorrect Predictions with Constant Perc. Error Threshold						
Threshold = 2.6%						
Statistic	0.104	0.0545	0.0782	0.0649	0.0340	0.129
Confidence Limits	0.0045	0.0024	0.0056	0.0026	0.0020	0.0030
Symmetric High-Low Loss Function						
Cutoff = 73 $\mu g/m^3$						
Statistic	0.127	0.0869	0.120	0.110	0.0704	0.0930
Confidence Limits	0.0067	0.0075	0.0051	0.0058	0.0053	0.0063

Table A-12

Accuracy Scores

Clifty Creek Network 1975

24 Hour Averages Background Included

CRSTER(Turner)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	20.7	12.3	16.3	14.3	8.10	12.7
Confidence Limits	4.34	3.38	3.39	3.18	0.999	2.09
Average Squared Error						
Statistic ($\mu g/m^3$)	1060	422	831	581	146	394
Confidence Limits	552	249	414	312	46.2	170
Fraction Incorrect						
Predictions with Absolute Error Thresholds						
Threshold = 2.6 $\mu g/m^3$						
Statistics	0.873	0.751	0.771	0.813	0.718	0.828
Confidence Limits	0.034	0.040	0.071	0.040	0.060	0.032
Fraction Incorrect						
Predictions with Constant Percentage Error Threshold						
Threshold = 2.6%						
Statistics	0.0603	0.0252	0.0332	0.0331	0.0063	0.0159
Confidence Limits	0.023	0.017	0.014	0.023	0.0081	0.011
Symmetric High-Low Loss Function						
Cutoff = 73 $\mu g/m^3$						
Statistic	0.133	0.110	0.133	0.0993	0.0381	0.0605
Confidence Limits	0.043	0.062	0.049	0.019	0.018	0.026

CRSTER (Irwin)	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Average Absolute Error						
Statistic ($\mu g/m^3$)	20.1	12.8	23.4	16.6	8.89	12.2
Confidence Limits	4.7	3.4	8.1	4.8	0.79	1.4
Average Squared Error						
Statistic	961	489	2060	1070	231	338
Confidence Limits	597	241	1550	844	22.8	148
Fraction Incorrect						
Predictions with Absolute Error Thresholds						
Threshold = 2.6 $\mu g/m^3$						
Statistics	0.879	0.745	0.787	0.802	0.714	0.828
Confidence Limits	0.027	0.053	0.045	0.033	0.064	0.022
Fraction Incorrect						
Predictions with Constant Perc. Error Threshold						
Threshold = 2.6%						
Statistic	0.0571	0.0347	0.0631	0.0404	0.0127	0.223
Confidence Limits	0.023	0.012	0.032	0.015	0.013	0.017
Symmetric High-Low Loss Function						
Cutoff = 73 $\mu g/m^3$						
Statistic	0.114	0.120	0.179	0.0993	0.0508	0.0541
Confidence Limits	0.039	0.073	0.047	0.026	0.026	0.020

Table A-13

1-Hour Contingency Table Summary

Statistic	Model	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Skill Score (Chance)	Turner	0.379	0.570	0.513	0.418	0.558	0.455
Skill Score (Background)	Turner	0.0023	0.013	0.028	0.039	0.0031	0.011
Gamma (Model) Asymptotic Standard Error	Turner	0.729 0.008	0.854 0.006	0.812 0.007	0.767 0.008	0.882 0.005	0.784 0.007
Gamma (Background) Asymptotic Standard Error		0.738	0.850	0.797	0.725	0.880	0.766
Fraction Correct (Model)	Turner	0.558	0.694	0.648	0.579	0.679	0.624
Fraction Correct (Background)		0.557	0.690	0.638	0.562	0.678	0.620
Correlation Coeff. (Model)	Turner	0.649	0.770	0.729	0.676	0.797	0.678
Correlation Coeff. (Background)		0.654	0.762	0.712	0.623	0.794	0.660
Skill Score (Chance)	Irwin	0.381	0.571	0.521	0.422	0.555	0.466
Skill Score (Background)	Irwin	0.0068	0.016	0.041	0.046	-0.0031	0.024
Gamma (Model) Asymptotic Standard Error	Irwin	0.731 0.008	0.856 0.006	0.821 0.006	0.771 0.007	0.874 0.005	0.804 0.007
Gamma (Background) Asymptotic Standard Error		0.738 0.008	0.850 0.006	0.797 0.007	0.725 0.008	0.880 0.005	0.766 0.008
Fraction Correct (Model	Irwin	0.560	0.695	0.653	0.582	0.677	0.629
Fraction Correct (Background)		0.557	0.690	0.638	0.562	0.678	0.620
Correlation Coeff. (Model)	Irwin	0.651	0.773	0.741	0.683	0.789	0.701
Correlation Coeff. (Background)		0.654	0.762	0.712	0.623	0.794	0.660

Table A-14

3-Hour Contingency Table Summary

Statistic	Model	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Camp Creek
Skill Score (Chance)	Turner	0.372	0.572	0.565	0.456	0.570	0.440
Skill Score (Background)	Turner	-0.0209	-0.0433	0.0203	0.0585	-0.0766	-0.0646
Gamma (Model) Asymptotic Standard Error	Turner	0.725 0.008	0.859 0.006	0.821 0.006	0.789 0.007	0.885 0.005	0.780 0.007
Gamma (Background) Asymptotic Standard Error		0.736 0.007	0.845 0.006	0.799 0.007	0.729 0.008	0.881 0.005	0.760 0.008
Fraction Correct (Model)	Turner	0.548	0.692	0.651	0.604	0.625	0.608
Fraction Correct (Background)		0.557	0.705	0.644	0.580	0.708	
Correlation Coeff. (Model)	Turner	0.650	0.781	0.741	0.707	0.804	0.677
Correlation Coeff. (Background)		0.657	0.760	0.714	0.633	0.799	0.657
Skill Score (Chance)	Irwin	0.375	0.574	0.538	0.454	0.569	0.455
Skill Score (Background)	Irwin	-0.0154	-0.0389	0.0447	0.0533	-0.0818	-0.0434
Gamma (Model) Asymptotic Standard Error	Irwin	0.727 0.008	0.859 0.006	0.838 0.006	0.791 0.007	0.878 0.005	0.807 0.007
Gamma (Background) Asymptotic Standard Error		0.736 0.007	0.845 0.006	0.799 0.007	0.729 0.008	0.881 0.005	0.760 0.008
Fraction Correct (Model	Irwin	0.551	0.694	0.662	0.602	0.684	0.615
Fraction Correct (Background)		0.557	0.705	0.644	0.580	0.708	0.631
Correlation Coeff. (Model)	Irwin	0.653	0.780	0.763	0.710	0.797	0.707
Correlation Coeff. (Background)		0.657	0.760	0.714	0.633	0.799	0.657

Table A-15

24-Hour Contingency Table Summary

Statistic	Model	Bacon Ridge	Rykers Ridge	North Madison	Hebron Church	Liberty Ridge	Canip Creek
Skill Score (Chance)	Turner	0.276	0.507	0.472	0.429	0.548	0.295
Skill Score (Background)	Turner	0.0189	0.0862	-0.0180	0.135	0.0101	0.0073
Gamma (Model) Asymptotic Standard Error (ASE)	Turner	0.635 0.048	0.823 0.031	0.783 0.039	0.791 0.035	0.914 0.022	0.696 0.049
Gamma (Background) Asymptotic Standard Error (ASE)		0.672 0.047	0.759 0.038	0.771 0.040	0.676 0.048	0.908 0.022	0.652 0.045
Fraction Correct (Model)	Turner	45.6	62.9	60.5	57.4	66.3	47.1
Fraction Correct (Background)		44.6	59.4	61.2	50.8	66.0	46.7
Correlation Coeff. (Model)	Turner	0.588	0.748	0.698	0.711	0.830	0.624
Correlation Coeff. (Background)		0.582	0.676	0.681	0.605	0.822	0.583
Skill Score (Chance)	Irwin	0.260	0.500	0.453	0.425	0.562	0.337
Skill Score (Background)	Irwin	0	0.0841	-0.0541	0.119	0.0303	0.0657
Gamma (Model) Asymptotic Standard Error	Irwin	0.625 0.049	0.828 01030	0.783 0.035	0.798 0.034	0.884 0.028	0.745 0.041
Gamma (Background) Asymptotic Standard Error		0.672 0.047	0.759 0.038	0.771 0.040	0.676 0.048	0.908 0.022	0.652 0.509
Fraction Correct (Model	Irwin	44.6	62.6	59.1	56.6	67.0	50.2
Fraction Correct (Background)		44.6	59.4	61.2	50.8	66.0	46.7
Correlation Coeff. (Model)	Irwin	0.550	0.754	0.712	0.719	0.804	0.667
Correlation Coeff. (Background)		0.582	0.675	0.681	0.605	0.822	0.583

were used to specify four categories. In general, statistics to analyze contingency tables require a minimum number of observations within each bin in the table, so a small number of categories was deliberately chosen to meet this requirement. The contingency table will have most of the observations in the cells along the major diagonal if the predictions and observations are well correlated. Panofsky and Brier[29] describe a number of easily-obtained scores that can be derived from a contingency table. For example the percentage correct can be obtained by summing the number of observation prediction pairs in the major diagonal and dividing by the total number of pairs. Most computer statistical packages offer a number of statistics for contingency table analysis.

A skill score(s) can also be derived from the information contained in a contingency table. The skill score is defined as

$$S = \frac{P - R}{T - R} \qquad \text{(A-11)}$$

where P is the number of correct forecasts, T is the total number of forecasts, and R is the number of correct predicted by a reference model. The score is equal to 1 when all forecasts are correct and is equal to zero when no correct forecasts are made. The expected number of correct predictions using background and chance as the baseline models were used to calculate 2 skill scores for each averaging time.

Three other statistics measuring association were evaluated for each contingency table: the Pearson correlation coefficient, the Gamma statistic, and the percent correct. The Pearson correlation coefficient (r) measures the degree of association between observed and predicted concentrations such that a value +1 indicates perfect and -1 indicates a perfect inverse correlation, with zero representing no correlation.

The Gamma statistic is a nonparametric measure of association that is based on the relative ordering of pairs of cases (e.g. hours). The Gamma statistic is defined as follows:

$$\text{Gamma} = \frac{C - Q}{C + Q} \qquad \text{(A-12)}$$

where C is the number of concordant pairs and Q is the number of discordant pairs, considering every possible pair of hours in the table. Like most other association measures, Gamma ranges from +1 to -1; a zero value of Gamma indicates no association, i.e. an equal or random pattern of agreement or disagreement.

The third association statistic, the percentage correct, is simple and provides a check on both Gamma and r. If the percentage correct is fairly large and both Gamma and r are close to +1, the model is probably doing well. Again, the most benefit of these statistics is in the relative comparison of their values for a baseline model compared to the values for the test model.

D. Model Algorithm Evaluation Statistics

Complete tables of the model algorithm results are also included in this appendix. Tables A-16 through A-21 list the complete systematic bias (average residuals) statistics for sorted meteorology. The sorted residuals are also listed in Tables A-22 through A-28.

Table A-16

One Hour Concentration Averages

NETWORK: Clifty Creek **YEAR:** 1975 **SITE:** Bacon Ridge

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	40.6	11.9	28.5	10.6	10.5	-2.02	-2.12
		1	40.5	18.0	25.6	2.38	0.872	-15.6	-17.2
		2	37.9	9.19	28.8	3.00	3.10	-6.34	-6.38
		3	37.2	10.3	26.5	9.80	4.14	-0.349	-6.75
		4	46.6	12.6	33.7	11.6	11.7	-1.75	-1.54
		5	40.9	12.7	28.2	10.9	11.7	-2.74	-1.89
		6	31.2	9.33	22.1	10.4	10.2	0.527	0.428
	A		43.6	4.13	44.5	29.8	38.6	39.8	38.2
	B		54.3	11.1	43.0	19.8	16.6	8.23	4.50
	C		61.7	22.9	37.3	21.3	17.7	-1.50	-4.32
	D		40.4	11.9	28.0	9.15	8.78	-3.67	-4.07
	E		36.2	10.6	25.5	14.6	19.8	3.58	8.24
	F		28.6	5.31	23.1	1.42	1.23	-3.93	-4.10
	G		28.4	9.24	18.9	0.00	0.00	-9.24	-9.24
-4			38.0	1.47	35.7	0.00	0.00	-1.47	-1.47
-3			24.0	6.83	17.5	0.00	0.00	-6.83	-6.83
-2			30.8	12.3	18.8	0.00	0.00	-12.3	-12.3
-1			64.1	35.5	28.6	0.179	0.276	-35.4	-35.3
0			83.7	46.4	37.8	69.9	69.2	22.2	21.5
1			30.4	-1.43	29.1	0.496	0.439	1.99	1.91
2			19.7	-2.32	21.9	0.00	0.0001	2.32	2.32
3			19.8	-1.65	21.4	0.00	0.00	1.65	1.65
4			17.9	-1.83	19.9	0.00	0.00	1.83	1.83

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	887.	763.	308.	880.	974.	885.	1010.
		1	556.	423.	195.	311.	82.8	311.	90.6
		2	371.	231.	217.	412.	386.	405.	378.
		3	611.	555.	224.	735.	480.	743.	373.
		4	887.	667.	257.	777.	974.	788.	950.
		5	788.	763.	308.	880.	961.	885.	1010.
		6	527.	514.	193.	596.	729.	609.	728.
	A		286.	257.	191.	410.	419.	486.	494.
	B		561.	539.	185.	880.	718.	885.	780.
	C		887.	763.	298.	777.	688.	788.	699.
	D		663.	590.	308.	735.	603.	743.	561.
	E		496.	392.	303.	693.	974.	695.	1010.
	F		373.	168.	205.	80.7	198.	120.	187.
	G		378.	254.	171.	0.00	0.00	107.	107.
-4			553.	441.	298.	0.00	0.00	284.	284.
-3			624.	469.	186.	0.00	0.00	101.	101.
-2			373.	221.	205.	0.00	0.0001	129.	129.
-1			788.	763.	308.	49.6	65.9	208.	206.
0			679.	590.	236.	880.	974.	885.	1010.
1			882.	295.	217.	77.3	48.0	206.	206.
2			485.	318.	167.	0.011	0.025	74.4	74.4
3			887.	667.	220.	0.00	0.00	72.2	72.2
4			543.	318.	256.	0.00	0.00	253.	253.

Table A-17

One Hour Concentration Averages

NETWORK: Clifty Creek YEAR: 1975 SITE: Rykers Ridge

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	36.8	9.44	28.5	7.88	10.6	-1.35	1.30
		1	32.2	6.02	25.6	0.524	1.94	-5.48	-4.02
		2	32.5	3.29	28.8	0.00	0.00	-3.29	-3.29
		3	41.7	15.0	26.5	3.52	4.83	-11.5	-10.5
		4	41.6	8.19	33.7	3.85	6.25	-5.81	-2.73
		5	37.2	9.30	28.2	11.6	15.3	1.47	4.86
		6	26.9	5.03	22.1	8.84	11.0	2.65	5.32
	A		45.5	6.04	44.5	90.3	68.7	106.	71.7
	B		56.9	13.8	43.0	38.7	31.5	25.0	16.6
	C		57.0	19.7	37.3	26.2	26.5	1.53	4.08
	D		36.9	8.94	28.0	4.37	9.33	-4.74	-0.0083
	E		28.0	2.56	25.5	1.08	5.56	-1.64	1.66
	F		26.2	3.15	23.1	0.0054	0.0363	-3.14	-3.11
	G		21.1	2.43	18.9	0.00	0.00	-2.43	-2.43
-4			32.7	-0.797	33.5	0.00	0.00	0.797	0.797
-3			30.1	7.64	22.4	0.00	0.00	-7.64	-7.64
-2			40.8	8.77	32.1	0.0009	0.012	-8.77	-8.77
-1			61.8	22.9	40.1	0.586	1.19	-22.4	-21.8
0			81.0	52.9	29.9	82.6	111.	26.5	55.8
1			28.0	5.94	21.9	1.02	1.91	-4.90	-4.32
2			21.6	0.0867	21.4	0.0391	0.065	-0.047	-0.051
3			25.2	0.775	24.3	0.00	0.00	-0.775	-0.775
4			20.7	-0.261	20.9	0.00	0.00	0.261	0.261

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	809.	770.	308.	1220.	1180.	1300.	1080.
		1	251.	86.1	185.	68.4	235.	73.7	246.
		2	381.	303.	217.	0.00	0.00	198.	198.
		3	647.	634.	224.	554.	973.	556.	730.
		4	585.	543.	257.	1220.	938.	1300.	832.
		5	809.	770.	308.	1220.	1180.	1150.	1080.
		6	683.	562.	193.	849.	747.	859.	723.
	A		308.	290.	191.	830.	531.	847.	552.
	B		582.	508.	185.	1220.	799.	1150.	729.
	C		765.	718.	290.	1220.	1180.	1300.	1080.
	D		809.	770.	308.	770.	973.	768.	837.
	E		352.	230.	303.	124.	856.	134.	867.
	F		472.	467.	285.	1.08	11.9	91.4	91.4
	G		235.	95.3	171.	0.00	0.00	50.5	50.5
-4			324.	200.	257.	0.00	0.00	107.	107.
-3			639.	476.	308.	0.00	0.01	57.4	57.4
-2			603.	562.	303.	0.35	4.45	191.	191.
-1			770.	688.	236.	68.5	130.	117.	121.
0			809.	770.	217.	1220.	1180.	1300.	1080.
1			326.	292.	167.	105.	107.	71.8	71.8
2			684.	526.	220.	18.8	9.10	118.	118.
3			496.	407.	256.	0.00	0.00	108.	108.
4			441.	325.	298.	0.00	0.00	242.	242.

Table A-18

One Hour Concentration Averages

NETWORK: Clifty Creek **YEAR:** 1975 **SITE:** North Madison

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	39.7	11.3	28.5	8.20	22.7	-3.37	10.6
		1	47.3	22.6	25.6	0.109	7.52	-22.5	-14.6
		2	40.9	11.8	28.8	0.0940	4.30	-11.8	-7.27
		3	41.6	15.0	26.5	1.43	2.78	-13.6	-12.0
		4	45.4	11.9	33.7	4.82	19.3	-7.34	7.51
		5	37.6	9.61	28.2	10.6	28.0	1.04	17.1
		6	33.6	11.6	22.1	11.9	26.9	-0.227	14.0
	A		52.0	12.3	44.5	77.7	61.2	64.4	46.2
	B		64.9	22.0	43.0	57.4	47.6	33.9	24.3
	C		58.2	21.0	37.3	35.5	56.6	16.8	38.4
	D		39.3	11.3	28.0	1.65	16.8	-9.85	4.52
	E		32.7	7.16	25.5	0.632	35.5	-6.55	26.3
	F		27.8	4.66	23.1	0.0002	0.0717	-4.66	-4.59
	G		25.6	6.56	18.9	0.00	0.00	-6.56	-6.56
-4			40.5	5.11	35.5	0.00	0.00	-5.11	-5.11
-3			23.4	0.523	22.8	0.0001	0.0004	-0.52	-0.52
-2			22.1	5.74	17.1	0.0008	0.032	-5.74	-5.71
-1			44.4	26.1	18.4	0.324	0.804	-25.8	-25.4
0			75.7	44.3	31.9	40.7	113.	-4.30	66.3
1			35.8	-5.30	41.9	1.83	3.79	7.12	9.24
2			28.8	-0.896	29.8	0.0834	0.334	0.987	1.26
3			23.8	-6.46	30.1	0.0002	0.007	6.46	6.47
4			20.6	-0.409	20.8	0.00	0.00	0.409	0.409

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	1770.	1670.	308.	1330.	1250.	1320.	1250.
		1	692.	689.	195.	5.4	319.	33.9	288.
		2	624.	621.	217.	10.7	389.	177.	380.
		3	1770.	1670.	224.	255.	991.	262.	945.
		4	947.	691.	257.	1280.	1180.	1260.	1120.
		5	1020.	736.	308.	1330.	1250.	1320.	1250.
		6	830.	792.	193.	1310.	1080.	1220.	1250.
	A		219.	161.	195.	1300.	730.	1320.	746.
	B		877.	792.	185.	1330.	933.	1240.	926.
	C		1770.	1670.	290.	1280.	1250.	1260.	1250.
	D		754.	736.	308.	338.	1050.	282.	945.
	E		864.	637.	303.	26.8	1180.	150.	1120.
	F		284.	248.	205.	0.02	6.82	157.	157.
	G		183.	105.	171.	0.00	0.00	93.1	93.1
-4			1020.	723.	298.	0.00	0.00	96.1	96.1
-3			206.	114.	231.	0.02	1.40	150.	150.
-2			144.	112.	171.	0.11	4.69	93.1	93.1
-1			653.	466.	205.	49.2	90.6	96.6	96.6
0			1770.	1670.	308.	1330.	1250.	1320.	1250.
1			240.	224.	201.	224.	236.	274.	312.
2			877.	692.	185.	29.6	98.8	128.	128.
3			133.	125.	217.	0.03	1.23	177.	177.
4			412.	297.	256.	0.00	0.00	228.	226.

Table A -19

One Hour Concentration Averages

NETWORK: Clifty Creek **YEAR: 1975** **SITE: Hebron Church**

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	37.4	9.03	28.5	14.3	18.2	5.20	9.0
		1	30.6	5.18	25.6	4.40	12.2	-0.437	7.96
		2	30.4	1.39	28.8	4.87	8.81	4.04	8.43
		3	34.1	7.68	26.5	7.89	2.33	-0.721	-5.20
		4	42.3	8.97	33.7	15.6	18.7	6.79	9.93
		5	37.2	9.24	28.2	16.4	21.6	6.78	12.0
		6	32.7	10.6	22.1	12.3	17.7	2.12	6.41
	A		58.5	20.5	44.5	30.1	27.0	8.31	4.55
	B		59.1	16.3	43.0	23.6	20.0	8.99	4.79
	C		51.1	13.5	37.3	37.5	26.7	27.8	15.0
	D		38.5	10.5	28.0	11.4	14.7	0.385	3.72
	E		30.2	4.92	25.5	19.3	46.0	14.2	40.6
	F		24.3	1.40	23.1	0.519	0.881	-0.932	-0.542
	G		22.0	3.54	18.5	0.00	0.00	-3.54	-3.54
-4			31.3	-3.63	34.8	0.00	0.00	3.63	3.63
-3			24.4	3.19	22.5	0.00	0.0001	-3.19	-3.19
-2			25.7	8.53	17.5	0.0007	0.0006	-8.53	-8.53
-1			35.5	17.7	18.8	0.0946	0.186	-17.6	-17.5
0			79.1	47.9	31.9	71.6	91.4	25.1	44.5
1			31.4	-4.95	37.0	0.253	0.435	5.18	5.34
2			26.3	-1.44	28.1	0.0005	0.0013	1.44	1.44
3			19.9	-2.40	21.9	0.00	0.00	2.40	2.40
4			22.0	0.311	21.5	0.00	0.00	-0.311	-0.311

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	976.	771.	308.	1320.	1090.	1330.	1050.
		1	295.	292.	195.	178.	520.	168.	510.
		2	227.	136.	217.	425.	793.	424.	785.
		3	616.	530.	224.	751.	655.	722.	649.
		4	577.	551.	257.	1320.	1090.	1330.	1010.
		5	976.	721.	308.	1120.	1030.	1260.	1050.
		6	809.	771.	193.	750.	952.	814.	948.
	A		492.	366.	191.	577.	514.	595.	532.
	B		809.	771.	186.	1120.	806.	1260.	798.
	C		713.	692.	290.	1320.	918.	1330.	921.
	D		976.	721.	308.	781.	696.	722.	688.
	E		676.	655.	303.	451.	1090.	484.	1050.
	F		224.	217.	205.	27.5	73.8	167.	167.
	G		157.	152.	171.	0.00	0.00	145.	145.
-4			300.	187.	290.	0.00	0.00	290.	290.
-3			251.	229.	146.	0.00	0.01	102.	102.
-2			303.	276.	186.	0.25	0.11	145.	145.
-1			512.	488.	205.	9.49	13.1	114.	114.
0			809.	771.	308.	1320.	1090.	1330.	1050.
1			399.	373.	201.	59.9	57.4	159.	171.
2			284.	260.	185.	0.10	0.23	104.	104.
3			107.	91.4	167.	0.00	0.00	67.9	67.9
4			976.	721.	256.	0.00	0.01	198.	198.

Table A-20

One Hour Concentration Averages

NETWORK: Clifty Creek **YEAR: 1975** **SITE: Liberty Ridge**

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	34.7	6.17	28.5	1.45	4.16	-4.78	-1.92
		1	31.8	6.23	25.6	0.00001	0.0928	-6.23	-6.13
		2	32.8	4.00	28.8	0.00001	0.00732	-4.00	-4.00
		3	30.2	3.65	26.5	0.0570	1.58	-3.59	-2.08
		4	41.6	7.85	33.7	0.444	2.06	-7.39	-5.78
		5	35.0	6.80	28.2	1.63	4.69	-5.45	-2.25
		6	25.5	3.27	22.1	3.25	7.71	0.559	5.70
	A		37.0	-3.85	44.5	14.7	17.0	10.9	17.8
	B		57.3	14.7	43.0	19.8	28.0	7.29	16.1
	C		45.8	8.21	37.3	3.42	14.4	-5.37	6.58
	D		34.0	5.73	28.0	0.0242	1.77	-5.70	-3.88
	E		31.2	5.57	25.5	0.0003	1.03	-5.57	-4.48
	F		28.1	5.00	23.1	0.00	0.00	-5.00	-4.99
	G		23.1	4.07	18.9	0.00	0.00	-4.07	-4.07
-4			32.9	3.94	28.9	0.00	0.00	-3.94	-3.94
-3			29.8	7.02	23.1	0.0004	0.0261	-7.02	-7.00
-2			25.6	3.84	21.3	0.0576	0.736	-3.78	-3.05
-1			38.7	17.6	20.0	2.83	9.61	-14.7	-7.94
0			39.7	22.1	17.2	24.9	72.5	1.53	49.9
1			33.8	17.7	16.9	3.82	6.59	-15.7	-12.3
2			25.9	8.94	16.4	0.0046	0.0665	-8.94	-8.87
3			45.0	13.9	30.8	0.0	0.0	-13.9	-13.9
4			37.9	4.40	33.5	0.00	0.00	-4.40	-4.40

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
*	*	*	692.	435.	308.	1340.	1530.	1320.	1490.
		1	271.	185.	195.	0.00	14.2	103.	103.
		2	217.	140.	217.	0.00	1.61	92.7	92.7
		3	284.	118.	224.	10.7	510.	95.5	499.
		4	692.	435.	257.	246.	435.	229.	421.
		5	467.	392.	308.	1250.	1530.	1160.	1490.
		6	398.	394.	193.	1340.	1420.	1320.	1400.
	A		128.	72.4	191.	449.	436.	302.	452.
	B		398.	394.	185.	1340.	1210.	1320.	1150.
	C		692.	435.	290.	886.	1530.	425.	1490.
	D		425.	376.	308.	19.6	693.	279.	694.
	E		467.	208.	303.	0.11	183.	177.	177.
	F		271.	89.3	285.	0.00	0.11	48.3	48.3
	G		217.	68.3	171.	0.00	0.00	50.5	50.5
-4			692.	435.	308.	0.00	0.00	279.	279.
-3			345.	278.	172.	0.07		170.	169.
-2			258.	198.	255.	9.04	3.24	253.	253.
-1			425.	376.	111.	186.	82.6	138.	182.
0			431.	394.	133.	1340.	188.	1320.	1490.
1			311.	305.	191.	449.	1530.	302.	452.
2			321.	209.	112.	0.53	436.	18.3	18.3
3			284.	257.	290.	0.00	6.40	154.	154.
4			347.	252.	257.	0.00	0.00	177.	177.
							0.00		

Table A-21

One Hour Concentration Averages

NETWORK: Clifty Creek **YEAR:** 1975 **SITE:** Canip Creek

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
•	•	•	29.9	1.16	28.5	2.80	4.01	1.31	2.83
		1	18.7	-6.87	25.6	0.00023	0.00029	6.87	6.87
		2	24.8	-4.12	28.8	0.00018	0.0251	4.12	4.15
		3	24.2	-2.34	26.5	0.0825	2.06	2.41	4.51
		4	35.4	1.48	33.7	0.997	2.15	-0.773	0.659
		5	30.4	2.02	28.2	3.58	4.73	1.47	2.73
		6	24.3	1.55	22.1	5.17	6.58	2.80	4.10
	A		59.8	15.3	44.5	25.2	19.5	11.7	5.53
	B		60.7	17.2	43.0	22.8	18.5	5.01	0.374
	C		43.8	6.00	37.3	12.6	15.0	4.60	8.27
	D		31.8	3.53	28.0	0.228	2.33	-3.31	-1.23
	E		19.0	-6.83	25.5	0.0019	0.486	6.83	7.35
	F		15.9	-7.60	23.1	0.00	0.00	7.60	7.60
	G		9.27	-9.84	18.9	0.00	0.00	9.84	9.84
-4			21.9	-6.50	28.3	0.00	0.00	6.50	6.50
-3			26.2	-10.9	37.0	0.00	0.00	10.9	10.9
-2			27.0	-1.23	28.1	0.0021	0.0181	1.23	1.25
-1			35.1	8.63	25.9	0.790	1.21	-7.75	-7.43
0			63.8	41.2	22.3	27.9	39.9	-16.9	-3.89
1			38.8	15.4	23.1	1.43	2.42	-14.2	-13.2
2			36.4	14.8	21.3	0.0119	0.0715	-14.8	-14.7
3			22.6	1.66	20.0	0.00	0.00	-1.66	-1.66
4			28.6	-3.45	31.5	0.00	0.00	3.45	3.45

Maximum One Hour Concentration Values

Wind Direction	Stability Class	Mixing Height Category	Observed With Background	Observed Without Background	Background	CRSTER (Turner) Predicted Without Background	CRSTER (Irwin) Predicted Without Background	CRSTER (Turner) Residual	CRSTER (Irwin) Residual
•	•	•	1360.	1340.	308.	903.	744.	758.	598.
		1	175.	162.	195.	0.035	0.045	171.	171.
		2	269.	253.	217.	0.036	5.08	190.	198.
		3	390.	380.	224.	18.1	434.	206.	357.
		4	1360.	1340	257.	733.	599.	657.	523.
		5	655.	637.	308.	903.	744.	758.	598.
		6	527.	517.	193.	749	523.	675.	504.
	A		363.	352.	191.	632.	357.	675.	309.
	B		655.	639.	185.	903.	744.	758.	598.
	C		1080.	1010.	290.	733.	649.	657.	523.
	D		676.	637.	308.	88.1	434.	234.	357.
	E		856.	792.	303.	0.32	154.	206.	206.
	F		1360.	1340.	205.	0.0	0.0	171.	171.
	G		123.	54.8	171.	0.0	0.	143.	133.
-4			507.	292.	308.	0.00	0.00	186.	186.
-3			386.	376.	201.	0.00	0.003	172.	172.
-2			425.	415.	185.	0.235	1.88	102.	102.
-1			676.	637.	217.	77.3	88.8	198.	199.
0			543.	527.	256.	903.	744.	758.	599.
1			600.	591.	172.	57.9	115.	164.	164.
2			1360.	1340	255.	2.22	8.86	234.	234.
3			475.	385.	111.	0.06	0.00	90.0	90.0
4			321.	196.	298.	0.00	0.00	206.	206.

Table A-22

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for Bacon Ridge Site in 1975.
Numbers in Parentheses Represent Number of Observations
Note that the Number of Observations is the Same for Both CRSTER Versions.

CRSTER (TURNER)	MIXING HEIGHT CATEGORIES						
	6	5	4	3	2	1	ALL
A	56.7 (6)	116 (9)	-- (0)	-- (0)	* (1)	-- (0)	84.1 (16)
B	39.0 (31)	38.0 (54)	-23.6 (19)	* (2)	* (2)	* (1)	24.1 (109)
C	14.8 (69)	-0.434 (120)	-3.40 (74)	* (18)	* (6)	* (2)	1.66 (289)
D	-16.0 (137)	-17.4 (573)	-8.36 (498)	2.84 (148)	* (39)	* (32)	-12.9 (1427)
E	10.9 (71)	4.50 (170)	49.0 (77)	5.50 (12)	23.8 (12)	9.35 (13)	16.3 (355)
F	-7.81 (128)	-2.28 (113)	-1.74 (46)	* (8)	13.3 (4)	-10.3 (8)	-4.45 (307)
G	* (54)	* (65)	* (21)	* (1)	- (0)	- (0)	* (141)
ALL	-0.862 (496)	-5.98 (1104)	-3.15 (735)	0.246 (189)	-6.84 (64)	-28.0 (56)	-4.27 (2644)

CRSTER (IRWIN)	MIXING HEIGHT CATEGORIES						
	6	5	4	3	2	1	ALL
A	56.6	108.	--	--	*	--	79.6
B	36.6	20.2	-42.8	*	*	*	11.4
C	11.1	-5.57	-23.3	*	*	*	-6.44
D	-14.6	-14.7	-7.92	-22.4	*	*	-14.1
E	11.4	22.4	76.3	5.58	24.3	-7.44	30.3
F	-8.10	-2.99	-1.51	*	9.85	-13.8	-4.94
G	*	*	*	*	--	--	*
ALL	-1.15	-3.37	-2.47	-19.5	-6.95	-32.4	-4.56

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind direction within 30° of the source-receptor centerline)

Table A-23

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for Rykers Ridge Site in 1975.
Numbers in Parentheses Represent Number of Observations.
Note that the Number of Observations is the same for Both CRSTER Versions.

CRSTER (TURNER)	MIXING HEIGHT CATEGORIES 6	5	4	3	2	1	ALL
A	423 (5)	261 (9)	-- (0)	-- (0)	* (1)	-- (0)	298 (15)
B	152 (23)	161 (44)	-17.8 (12)	* (1)	* (2)	* (1)	121 (83)
C	13.4 (54)	61.6 (82)	-12.5 (47)	* (10)	* (4)	* (2)	25.5 (199)
D	-13.7 (100)	-14.9 (425)	-17.0 (337)	-48.0 (91)	* (21)	* (23)	-18.6 (997)
E	5.57 (52)	-2.76 (108)	-16.6 (48)	-0.37 (7)	* (5)	7.49 (6)	-3.62 (226)
F	-11.3 (67)	-7.20 (84)	* (23)	* (3)	* (4)	* (5)	-7.64 (186)
G	* (35)	* (50)	* (16)	* (1)	-- (0)	-- (0)	* (102)
ALL	12.5 (336)	8.99 (802)	-15.5 (483)	-43.4 (113)	-9.56 (37)	-12.1 (37)	-0.978 (1808)

CRSTER (IRWIN)	MIXING HEIGHT CATEGORIES 6	5	4	3	2	1	ALL
A	340.	134.	--	--	*	--	194
B	153.	103.	-73.8	*	*	*	82.6
C	60.9	81.1	-55.2	*	*	*	36.3
D	1.36	10.3	6.21	-43.2	*	*	1.92
E	8.21	24.2	-14.0	23.9	*	43.5	12.1
F	-11.2	-6.97	*	*	*	*	-7.49
G	*	*	*	*	--	--	*
ALL	23.9	23.4	-4.58	-38.0	-9.56	-6.27	10.9

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline)

Table A-24

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for North Madison Site in 1975. Numbers in Parentheses Represent Number of Observations. Note that the Number of Observations is the Same for Both CRSTER Versions.

CRSTER (Turner)	Mixing Height Categories						
	6	5	4	3	2	1	All
A	240 (2)	542 (5)	-- (0)	-- (0)	-- (0)	-- (0)	456 (7)
B	267 (20)	273 (37)	-33.9 (18)	* (1)	* (1)	* (1)	189 (78)
C	61.4 (55)	123 (104)	58.7 (77)	* (21)	* (7)	* (2)	64.6 (266)
D	-20.6 (128)	-28.6 (466)	-38.9 (436)	-23.2 (132)	* (39)	* (30)	-33.0 (1231)
E	-15.5 (71)	-21.4 (187)	-16.0 (79)	-7.84 (15)	-5.74 (14)	-21.6 (13)	-18.0 (379)
F	-9.65 (110)	-12.8 (126)	-9.63 (45)	-5.22 (9)	-2.98 (7)	-10.4 (14)	-10.7 (311)
G	* (56)	* (79)	* (18)	-- (0)	-- (0)	-- (0)	* (153)
All	7.83 (442)	5.88 (1004)	-22.5 (673)	-37.4 (178)	-34.5 (68)	-48.7 (60)	-7.30 (2425)
CRSTER (Irwin)	**Mixing Height Categories**						
A	331	328	--	--	--	--	329
B	243	203	-66.2	*	*	*	142
C	213	264	-4.95	*	*	*	133
D	13.3	33.6	25.7	-19.1	*	*	17.4
E	89.4	54.1	123	15.3	56.8	65.6	73.9
F	-9.51	-12.6	-9.22	-5.04	-2.98	-10.4	-10.4
G	*	*	*	--	--	--	*
All	7.83	59.8	27.5	-32.5	-21.6	-29.8	38.3

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline).

Table A-25

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for Hebron Church Site in 1975.
Numbers in Parentheses Represent Number of Observations.
Note that the Number of Observations is the Same for Both CRSTER Versions.

CRSTER (Turner)	Mixing Height Categories 6	5	4	3	2	1	All
A	3.22 (2)	119 (6)	-- (0)	-- (0)	* (1)	-- (0)	81.7 (9)
B	6.18 (24)	110 (36)	-66.2 (19)	* (2)	* (2)	* (1)	35.2 (84)
C	55.8 (65)	102 (110)	84.7 (83)	* (19)	* (6)	* (3)	72.6 (286)
D	-3.32 (144)	-3.83 (499)	2.54 (442)	3.87 (141)	* (40)	* (30)	-1.20 (1296)
E	61.1 (74	31.6 (185)	40.0 (79)	10.2 (13)	73.8 (14)	14.7 (12)	39.4 (377)
F	-5.44 (126)	-0.231 (116)	5.86 (44)	5.31 (8)	-6.20 (5)	-7.56 (11)	-1.69 (310)
G	* (55)	* (74)	* (13)	-- (0)	-- (0)	-- (0)	* (142)
All	13.8 (490)	19.0 (1026)	15.1 (680)	-1.92 (183)	8.69 (68)	-4.97 (57)	14.6 (2504)

CRSTER (Irwin)	Mixing Height Categories 6	5	4	3	2	1	All
A	1.75	92.7	--	--	*	--	63.7
B	19.3	63.1	-76.2	*	*	*	16.4
C	52.0	78.1	-10.4	*	*	*	34.9
D	5.18	16.1	16.9	-17.2	*	*	10.0
E	126	96.0	150	40.1	136	114	113
F	-4.71	0.967	8.40	4.66	-6.24	-7.54	-0.606
G	*	*	*	--	--	--	*
All	26.5	36.1	25.5	-16.0	21.4	16.0	26.7

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline)

Table A-26

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for Liberty Ridge Site in 1975. Numbers in Parentheses Represent Number of Observations. Note that the Number of Observations is the Same for both CRSTER Versions.

CRSTER (TURNER)	MIXING HEIGHT CATEGORIES						
	6	5	4	3	2	1	ALL
A	302 (1)	-- (0)	-- (0)	-- (0)	-- (0)	-- (0)	302 (1)
B	186 (19)	119 (19)	-78.2 (10)	-- (0)	-- (0)	-- (0)	104 (48)
C	-8.59 (26)	-28.2 (41)	-12.2 (19)	* (4)	-- (0)	-- (0)	-17.8 (90)
D	-17.0 (39)	-21.1 (141)	-12.4 (242)	-13.1 (39)	* (13)	* (6)	-15.7 (480)
E	-2.57 (30)	-6.01 (56)	-10.9 (23)	* (4)	* (2)	-75.2 (1)	-6.99 (116)
F	* (23)	-4.50 (30)	* (11)	-- (0)	* (1)	* (1)	-4.90 (66)
G	* (9)	* (12)	* (1)	-- (0)	-- (0)	-- (0)	* (22)
ALL	18.7 (147)	-8.09 (299)	-14.6 (306)	-11.4 (47)	-18.9 (16)	-28.8 (8)	-6.32 (823)
CRSTER (IRWIN)	MIXING HEIGHT CATEGORIES						
A	452	--	--	--	--	--	452
B	327	160	-95.0	--	--	--	173
C	128	135	-5.61	*	--	--	97.1
D	-3.81	-1.07	3.20	10.9	*	*	1.03
E	11.7	6.35	-8.48	*	*	-61.0	3.28
F	*	-4.49	*	--	*	*	-4.90
G	*	*	*	--	--	--	*
ALL							21.6

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline)

Table A-27

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for Canip Creek Site in 1975. Numbers in Parentheses Represent Number of Observations. Note that the Number of Observations is the same for Both CRSTER Versions.

CRSTER (Turner)	Mixing Height Categories						
	6	5	4	3	2	1	All
A	115 (5)	-24.1 (7)	-- (0)	-- (0)	-- (0)	-- (0)	34.0 (12)
B	109 (22)	23.6 (40)	11.3 (7)	-- (0)	-- (0)	-- (0)	49.6 (69)
C	31.7 (36)	31.2 (64)	57.7 (16)	* (3)	* (2)	-- (0)	34.0 (121)
D	-26.4 (122)	-31.5 (381)	-28.4 (314)	-42.4 (82)	* (34)	* (13)	-30.6 (946)
E	8.65 (22)	-2.86 (70)	2.81 (32)	* (5)	-3.52 (4)	14.1 (3)	1.44 (136)
F	* (25)	* (55)	* (16)	* (4)	* (2)	* (0)	* (102)
G	* (11)	* (23)	* (10)	* (2)	* (0)	* (0)	* (46)
All	5.32 (243)	-13.7 (640)	-19.8 (395)	-33.1 (96)	-25.7 (42)	* (16)	-13.8 (1432)
CRSTER (Irwin)	Mixing Height Categories						
A	59.2	-27.6	--	--	--	--	8.55
B	87.1	-9.66	10.9	--	--	--	23.3
C	91.4	52.9	34.5	*	*	*	60.2
D	-22.3	-21.6	-17.0	-27.4	*	*	-21.0
E	9.18	3.85	5.25	*	-2.156	14.1	5.60
F	*	*	*	*	*	*	*
G	*	*	*	*	*	*	*
All	13.2	-7.03	-11.4	-20.3	-25.5	-10.1	-6.28

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline)

Table A-28

Clifty Creek Network Sorted Hourly Residuals ($\mu g/m^3$) for Hours When Maximum Impact is Likely for All Combined Sites in 1975.
Numbers in Parentheses Represent Number of Observations.
Note that the Number of Observations is the Same for Both CRSTER Versions.

CRSTER (Turner)	Mixing Height Categories						
	6	5	4	3	2	1	All
A	182 (21)	185 (36)	-- (0)	-- (0)	* (3)	-- (0)	174 (60)
B	116 (273)	115 (91)	-38.0 (8)	* (7)	* (4)	* (21)	82.4 (471)
C	31.7 (305)	57.3 (521)	36.1 (316)	* (75)	* (25)	* (9)	36.8 (1251)
D	-15.7 (670)	-18.7 (2485)	-16.6 (2269)	-16.5 (633)	* (186)	* (134)	-18.1 (6377)
E	14.4 (320)	2.29 (776)	13.9 (338)	2.40 (56)	22.1 (51)	0.618 (48)	7.79 (1589)
F	-7.04 (479)	-4.28 (524)	-1.30 (185)	2.18 (32)	0.963 (23)	-10.9 (39)	-4.83 (1282)
G	* (220)	* (303)	* (79)	* (4)	-- (0)	-- (0)	* (606)
All	8.39 (2154)	3.04 (4875)	-8.22 (3272)	-19.3 (806)	-13.3 (295)	-24.0 (234)	-1.64 (11636)
CRSTER (Irwin)	Mixing Height Categories						
A	164	116	--	--	*	--	127
B	130	78.5	-61.3	*	*	*	64.7
C	84.5	97.8	-16.2	*	*	*	53.3
D	-3.41	4.54	5.41	-22.1	*	*	-0.482
E	54.6	45.0	79.0	18.6	56.5	49.3	53.7
F	-6.88	-4.08	-0.544	2.07	0.353	-11.6	-4.61
G	*	*	*	*	--	--	*
All	26.5	23.8	8.16	-22.6	-7.41	-14.1	15.1

* No observations

-- Neither CRSTER(Turner) or CRSTER(Irwin) predicted a significant impact during the hours with possible impact (wind dir. within 30° of the source-receptor centerline)

Tables A-29 through A-31 list correlation coefficients between observed and predicted concentrations for all three averaging times. Finally all 6 scatter diagrams of 24-hour observed vs predicted concentrations with superimposed regression lines are shown in Figures A-1 through A-6.

Table A-29

One Hour Concentration Correlation Coefficients

Clifty Creek Network - 1975

	CRSTER (Turner)		CRSTER (Irwin)		
Monitoring Site	Without Background	With Background	Without Background	With Background	Background Only
Bacon Ridge	0.142	0.359	0.158	0.369	0.538
Rykers Ridge	0.172	0.382	0.217	0.406	0.523
North Madison	0.126	0.313	0.197	0.323	0.517
Hebron Church	0.275	0.397	0.293	0.402	0.392
Liberty Ridge	0.0702	0.614	0.0746	0.469	0.763
Canip Creek	0.143	0.367	0.210	0.417	0.393

All coefficients are significant i.e. in all cases the distributions are different

Table A-30

Three Hour Concentration Correlation Coefficients

Clifty Creek Network - 1975

	CRSTER (Turner)		CRSTER (Irwin)		
Monitoring Site	Without Background	With Background	Without Background	With Background	Background Only
Bacon Ridge	0.186	0.456	0.204	0.459	0.593
Rykers Ridge	0.251	0.520	0.301	0.545	0.593
North Madison	0.179	0.429	0.266	0.425	0.580
Hebron Church	0.379	0.533	0.374	0.511	0.455
Liberty Ridge	0.111	0.730	0.111	0.613	0.809
Canip Creek	0.218	0.483	0.293	0.535	0.455

All coefficients are significant i.e. in all cases the distributions are different

Table A-31

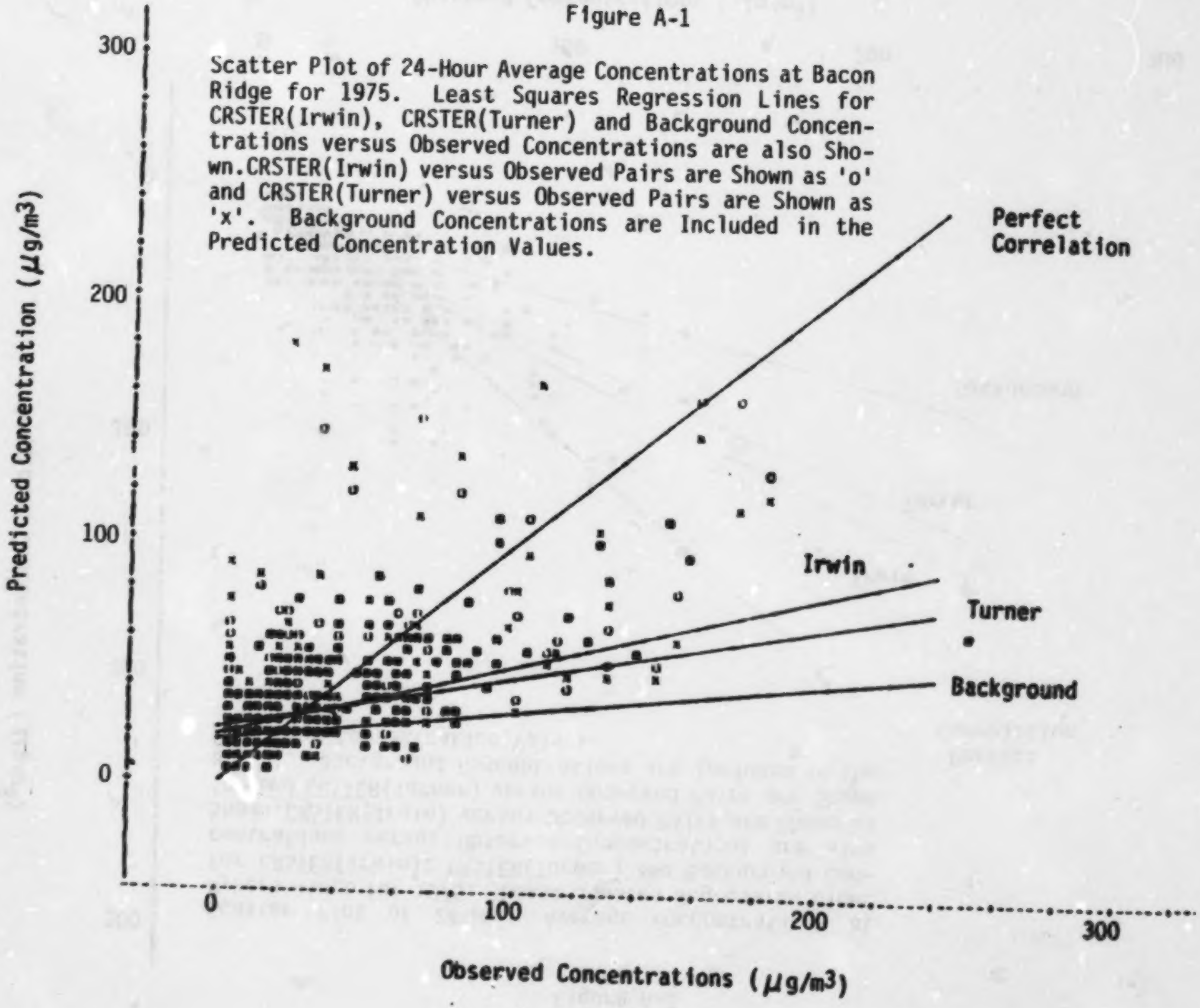
Twenty Four Hour Concentration Correlation Coefficients

Clifty Creek Network - 1975

	CRSTER (Turner)		CRSTER (Irwin)		
Monitoring Site	**Without Background**	**With Background**	**Without Background**	**With Background**	**Background Only**
Bacon Ridge	0.228	0.558	0.314	0.604	0.619
Rykers Ridge	0.299	0.710	0.305	0.690	0.690
North Madison	0.173	0.567	0.283	0.498	0.659
Hebron Church	0.496	0.716	0.506	0.682	0.584
Liberty Ridge	0.0806*	0.887	0.0157*	0.801	0.897
Canip Creek	0.140	0.568	0.250	0.641	0.611

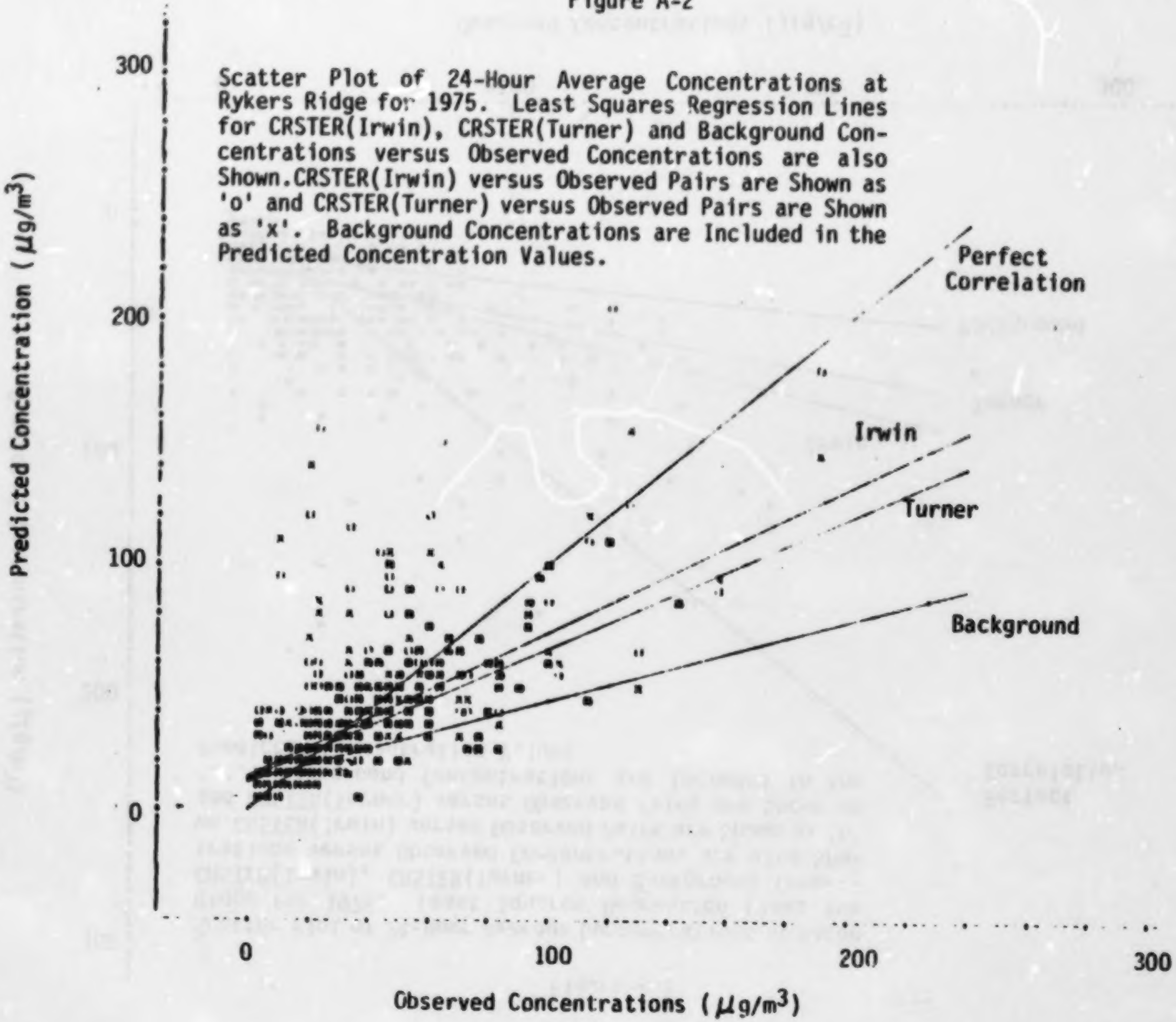
*All coefficients are significant i.e. the distributions are different except those that are marked by an asterix.

Figure A-1



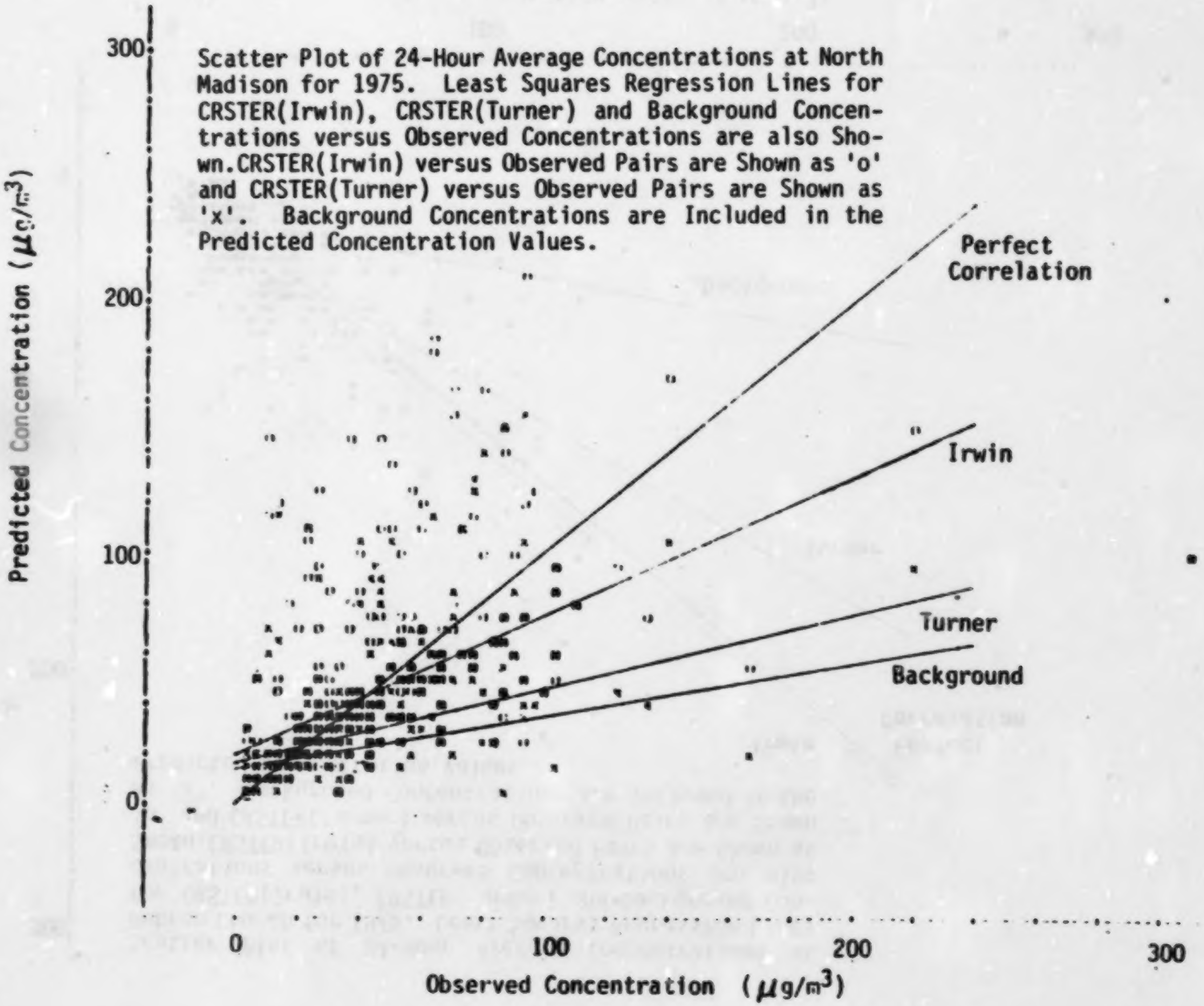
Scatter Plot of 24-Hour Average Concentrations at Bacon Ridge for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown. CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

Figure A-2



Scatter Plot of 24-Hour Average Concentrations at Rykers Ridge for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown. CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

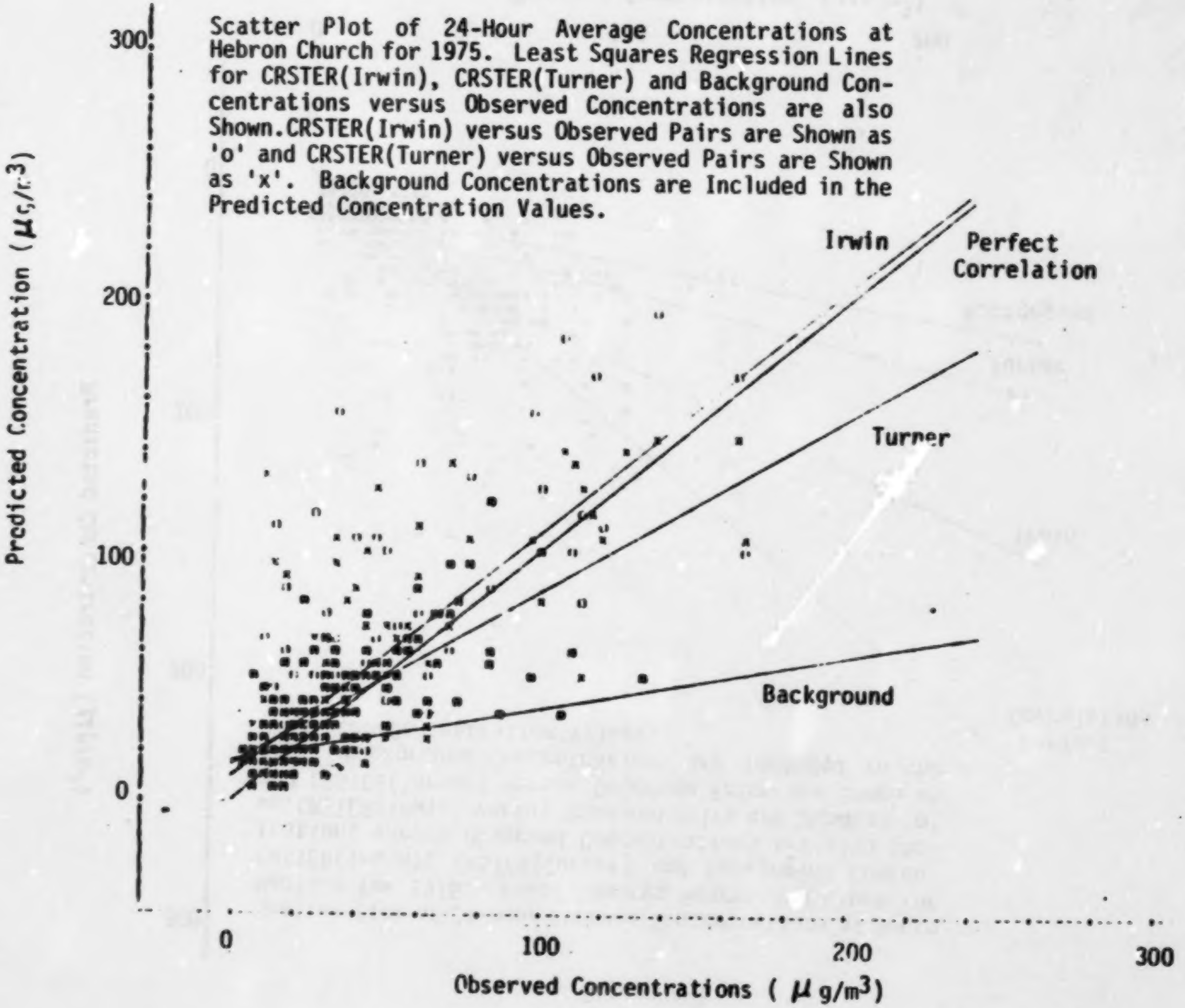
Figure A-3



Scatter Plot of 24-Hour Average Concentrations at North Madison for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown.CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

Predicted Concentration ($\mu g/m^3$)
300
200
100
0
Observed Concentration ($\mu g/m^3$)
0
100
200
300
Perfect Correlation
Irwin
Turner
Background

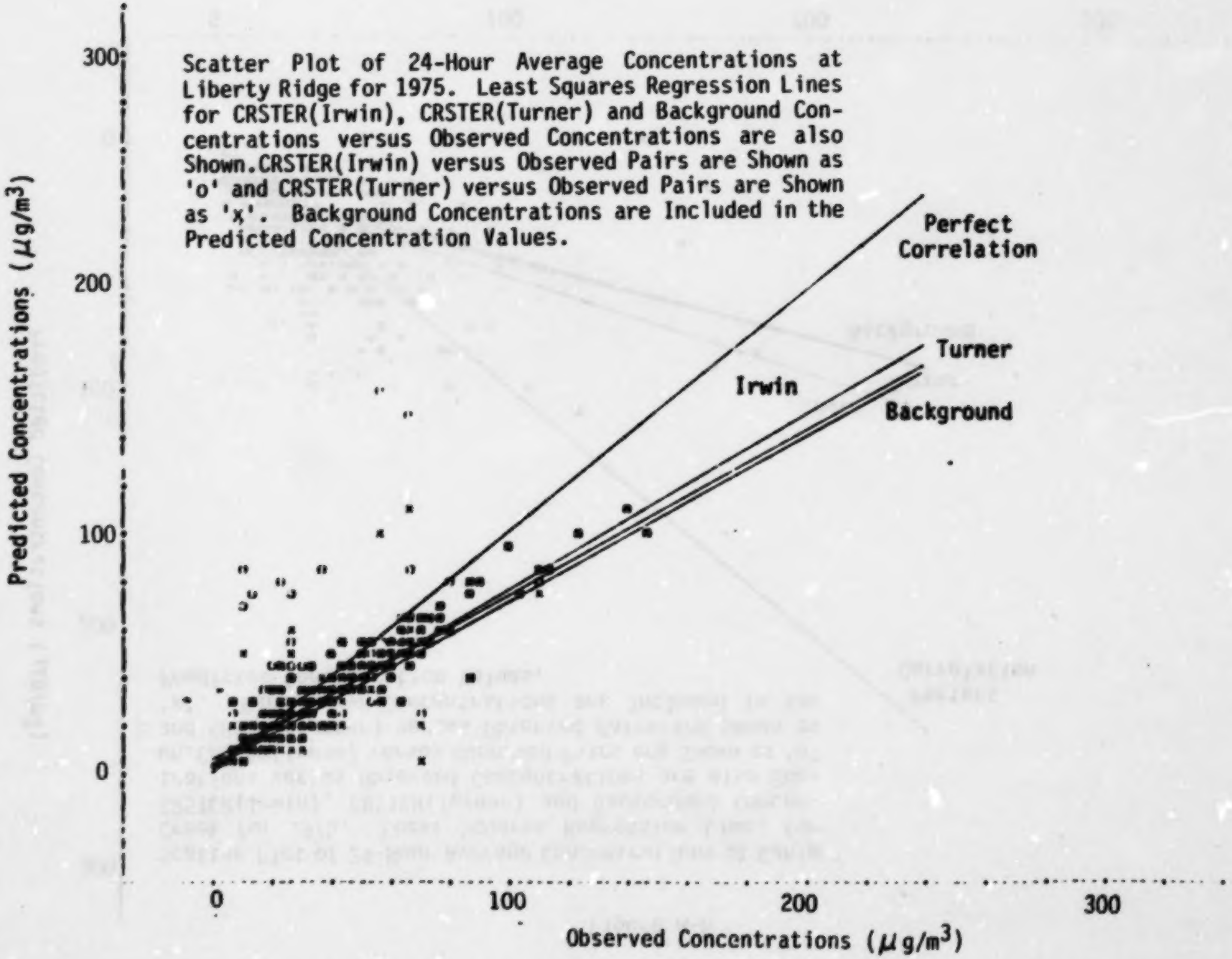
Figure A-4



Scatter Plot of 24-Hour Average Concentrations at Hebron Church for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown. CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

Predicted Concentration ($\mu g/m^3$)
300
200
100
0
Irwin
Perfect Correlation
Turner
Background
0
100
200
300
Observed Concentrations ($\mu g/m^3$)

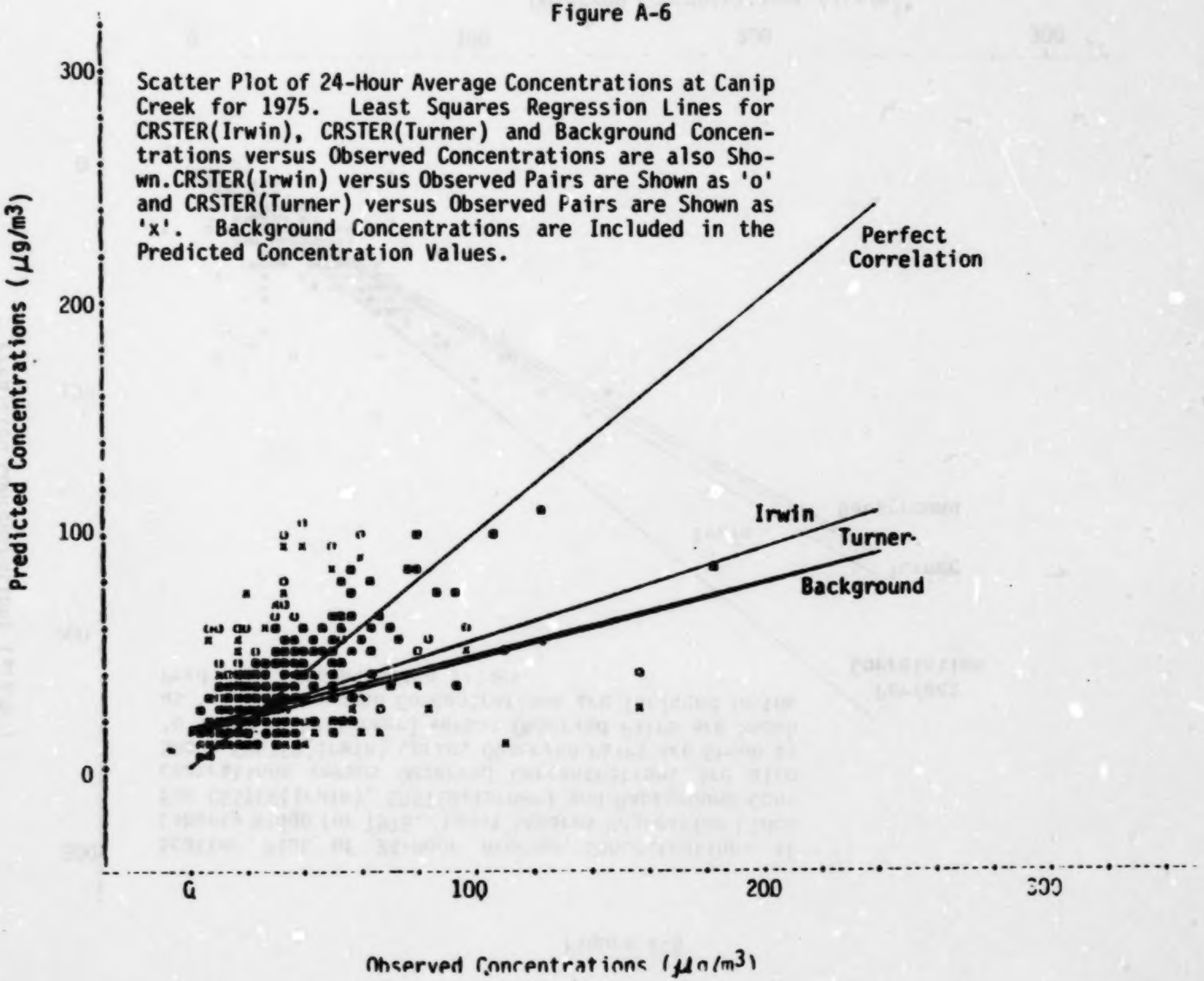
Figure A-5



Scatter Plot of 24-Hour Average Concentrations at Liberty Ridge for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown. CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

Predicted Concentrations ($\mu g/m^3$)
300
200
100
0
0
100
200
300
Observed Concentrations ($\mu g/m^3$)
Perfect Correlation
Turner
Irwin
Background

Figure A-6



Scatter Plot of 24-Hour Average Concentrations at Canip Creek for 1975. Least Squares Regression Lines for CRSTER(Irwin), CRSTER(Turner) and Background Concentrations versus Observed Concentrations are also Shown. CRSTER(Irwin) versus Observed Pairs are Shown as 'o' and CRSTER(Turner) versus Observed Pairs are Shown as 'x'. Background Concentrations are Included in the Predicted Concentration Values.

Predicted Concentrations (μg/m3)
300
200
100
0
Observed Concentrations (μg/m3)
0
100
200
300
Perfect Correlation
Irwin
Turner
Background

Appendix B

Times, Locations and Concentrations for Measured and Calculated 3-Hour and 24-Hour SO_2 Episodes at the 4 AEP Networks

Table B-1. Measured Episodes for Clifty Creek

3-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
23 JAN 1975	5	1075.00 (1062)	D8
24 JAN 1975	14	1031.00 (968)	D3
23 JAN 1975	19	795.00 (676)	D3
23 APR 1975	15	664.00 (641)	D3
25 FEB 1975	10	659.00 (649)	D2
22 DEC 1975	16	643.00 (601)	D8
3 NOV 1975	13	638.00 (574)	D1
4 MAR 1975	14	622.00 (605)	D8
16 APR 1975	15	613.00 (516)	D4
21 OCT 1975	13	560.00 (492)	D1
4 JUN 1975	10	559.00 (509)	D4
27 FEB 1975	15	540.00 (536)	D8
22 OCT 1975	11	540.00 (476)	D1
11 JAN 1975	9	532.00 (521)	D2
29 AUG 1975	12	532.00 (490)	D1
28 APR 1975	17	531.00 (460)	D1
7 FEB 1975	14	526.00 (513)	D2
20 FEB 1975	13	520.00 (417)	D1
21 MAR 1975	13	517.00 (506)	D4
24 JAN 1975	9	517.00 (491)	D1
24 JAN 1975	1	514.00 (414)	D3
1 APR 1975	15	513.00 (497)	D3
20 FEB 1975	16	510.00 (418)	D2
17 JAN 1975	13	498.00 (431)	D3
2 APR 1975	12	494.00 (479)	D4

(D1)	Bacon Ridge	7
(D2)	Rykers Ridge	4
(D3)	N. Madison	6
(D4)	Hebron Church	4
(D5)	Liberty Ridge	0
(D8)	Canip Creek	4

24-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
24 JAN 1975	24	309.00 (234)	D3
21 OCT 1975	24	252.00 (199)	D1
22 OCT 1975	24	250.00 (195)	D1
23 JAN 1975	24	221.00 (148)	D3
25 FEB 1975	24	189.00 (173)	D2
2 NOV 1975	24	183.00 (140)	D1
15 NOV 1975	24	172.00 (129)	D1
23 APR 1975	24	166.00 (159)	D3
19 DEC 1975	24	161.00 (111)	D1
8 FEB 1975	24	158.00 (110)	D2
13 DEC 1975	24	156.00 (138)	D4
7 OCT 1975	24	155.00 (122)	D1
4 MAR 1975	24	155.00 (146)	D8
1 NOV 1975	24	155.00 (135)	D1
1 APR 1975	24	151.00 (84)	D1
11 DEC 1975	24	148.00 (108)	D1
11 MAR 1975	24	145.00 (117)	D5
28 APR 1975	24	141.00 (107)	D1
7 DEC 1975	24	139.00 (93)	D5
5 MAR 1975	24	136.00 (115)	D4
21 JAN 1975	24	135.00 (110)	D3
16 NOV 1975	24	133.00 (88)	D2
4 JUN 1975	24	132.00 (103)	D4
8 NOV 1975	24	131.00 ( )	D1
11 JAN 1975	24	131.00 (124)	D2

(D1)	Bacon Ridge	11
(D2)	Rykers Ridge	4
(D3)	N. Madison	4
(D4)	Hebron Church	3
(D5)	Liberty Ridge	2
(D8)	Canip Creek	1

Note: On Tables B-1 through B-4, the handwritten numbers in parentheses are concentrations with the estimated background subtracted out.

Table B-1(continued)

3-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
28 OCT 1976	16	813.00(797)	D8
9 MAY 1976	17	739.00(690)	D2
12 OCT 1976	13	721.00(657)	D1
22 APR 1976	10	693.00(650)	D2
2 NOV 1976	14	677.00(572)	D1
27 DEC 1976	15	675.00(617)	D4
19 FEB 1976	7	672.00(648)	D4
22 MAY 1976	17	671.00(644)	D2
13 OCT 1976	3	655.00(601)	D1
13 AUG 1976	15	644.00(638)	D2
15 OCT 1976	9	631.00(576)	D1
19 APR 1976	14	627.00(51[illegible])	D2
24 FEB 1976	13	619.00(606)	D1
28 OCT 1976	13	619.00(597)	D5
16 NOV 1976	17	612.00(523)	D8
15 DEC 1976	16	601.00(499)	D1
7 MAY 1976	12	600.00(555)	D4
5 OCT 1976	13	594.00(581)	D3
15 JUL 1976	14	590.00(570)	D2
11 AUG 1976	13	584.00(581)	D4
1 NOV 1976	16	580.00(574)	D2
24 APR 1976	12	569.00(534)	D4
23 JAN 1976	14	560.00(495)	D1
12 FEB 1976	14	553.00(546)	D4
18 JAN 1976	16	551.00(472)	D3

(D1) Bacon Ridge 7
(D2) Rykers Ridge 7
(D3) N. Madison 2
(D4) Hebron Church 6
(D5) Liberty Ridge 1
(D8) Canip Creek 2

24-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
25 NOV 1976	24	211.00(189)	D4
17 OCT 1976	24	197.00(156)	D1
24 FEB 1976	24	191.00(144)	D4
17 NOV 1976	24	187.00(171)	D2
23 JAN 1976	24	177.00(129)	D1
9 MAY 1976	24	177.00(121)	D2
24 APR 1976	24	169.00(151)	D4
22 DEC 1976	24	168.00(96)	D4
15 DEC 1976	24	166.00(110)	D1
14 DEC 1976	24	165.00(99)	D1
27 FEB 1976	24	166.00(134)	D1
25 FEB 1976	24	164.00(150)	D4
2 NOV 1976	24	164.00(100)	D1
5 MAY 1976	24	162.00(126)	D4
15 JUN 1976	24	161.00(136)	D3
6 NOV 1976	24	157.00(127)	D1
27 DEC 1976	24	157.00(132)	D4
28 OCT 1976	24	154.00(131)	D5
22 APR 1976	24	151.00(141)	D2
21 JUL 1976	24	146.00(104)	D1
16 NOV 1976	24	145.00(51)	D8
3 AUG 1976	24	144.00(103)	D5
24 AUG 1976	24	140.00(59)	D8
14 NOV 1976	24	139.00(116)	D2
19 FEB 1976	24	138.00(115)	D4

(D1) Bacon Ridge 8
(D2) Rykers Ridge 4
(D3) N. Madison 1
(D4) Hebron Church 8
(D5) Liberty Ridge 2
(D8) Canip Creek 2

Table B-2 Measured Episodes for Tanners Creek

3-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
3 OCT 1975	14	1101.00 ([illegible])	C5
3 OCT 1975	17	1007.00 (996)	C5
15 FEB 1975	18	892.00 (877)	C6
17 APR 1975	22	884.00 (861)	C6
23 NOV 1975	18	844.00 (633)	C1
5 MAY 1975	23	813.00 (796)	C6
5 MAR 1975	21	786.00 (741)	C6
15 DEC 1975	3	776.00 (760)	C6
20 DEC 1975	1	773.00 (750)	C6
18 APR 1975	10	767.00 (751)	C6
7 APR 1975	14	764.00 (744)	C4
21 FEB 1975	21	762.00 (752)	C5
18 APR 1975	16	751.00 (748)	C6
17 OCT 1975	15	746.00 (719)	C5
14 DEC 1975	13	739.00 (730)	C6
21 MAR 1975	17	698.00 (612)	C6
24 JAN 1975	9	694.00 (601)	C6
7 OCT 1975	18	692.00 (665)	C5
17 APR 1975	19	687.00 (664)	C6
24 APR 1975	7	684.00 (663)	C6
7 DEC 1975	15	684.00 (667)	C1
7 MAR 1975	4	679.00 (673)	C6
4 SEP 1975	14	678.00 (674)	C4
9 SEP 1975	14	673.00 (652)	C1
24 JAN 1975	12	669.00 (564)	C6

(C1) Dutch Hollow 3
(C4) Petersburg 2
(C5) Wilson Creek 5
(C6) Lawrenceburg 15
(C7) Elizabethtown 0
(C8) Kilby Road 0

24-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
18 APR 1975	24	532.00 (523)	C6
24 JAN 1975	24	409.00 (417)	C6
6 MAR 1975	24	351.00 (271)	C6
5 MAR 1975	24	325.00 (291)	C6
17 APR 1975	24	321.00 (307)	C6
14 DEC 1975	24	299.00 (252)	C6
3 OCT 1975	24	295.00 (269)	C5
23 JAN 1975	24	289.00 (219)	C6
23 NOV 1975	24	276.00 (271)	C1
29 APR 1975	24	275.00 (253)	C6
15 FEB 1975	24	273.00 (223)	C6
7 DEC 1975	24	272.00 (262)	C1
23 APR 1975	24	270.00 (263)	C6
7 MAR 1975	24	259.00 (246)	C6
5 MAY 1975	24	254.00 (226)	C6
21 FEB 1975	24	254.00 (237)	C5
21 JAN 1975	24	251.00 (229)	C6
19 DEC 1975	24	242.00 (203)	C6
30 MAY 1975	24	242.00 (236)	C6
26 APR 1975	24	237.00 (213)	C6
16 MAY 1975	24	223.00 (211)	C1
14 JUN 1975	24	221.00 (199)	C6
20 DEC 1975	24	210.00 (176)	C6
20 MAY 1975	24	205.00 (184)	C6
9 SEP 1975	24	201.00 (189)	C1

(C1) Dutch Hollow 4
(C4) Petersburg 0
(C5) Wilson Creek 2
(C6) Lawrenceburg 19
(C7) Elizabethtown 0
(C8) Kilby Road 0

Table B-2 (continued)

3-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
26 NOV 1976	4	1293.00 (1296)	C6
25 NOV 1976	24	1264.00 (1272)	C6
25 NOV 1976	19	1058.00 (1021)	C6
25 NOV 1976	16	936.00 (917)	C6
13 APR 1976	15	898.00 (857)	C5
12 MAR 1976	15	795.00 (791)	C6
9 NOV 1976	6	753.00 (733)	C6
16 AUG 1976	14	718.00 (697)	C1
21 AUG 1976	15	702.00 (664)	C1
5 OCT 1976	1	702.00 (699)	C5
14 NOV 1976	18	660.00 (487)	C7
20 MAR 1976	15	645.00 (616)	C6
5 JUL 1976	11	641.00 (617)	C1
16 SEP 1976	13	624.00 (566)	C4
29 MAR 1976	9	622.00 (558)	C5
14 NOV 1976	15	620.00 (391)	C7
5 OCT 1976	13	608.00 (579)	C6
28 OCT 1976	22	569.00 (558)	C1
13 APR 1976	12	569.00 (543)	C5
17 APR 1976	18	566.00 (550)	C4
10 AUG 1976	17	548.00 (503)	C5
10 AUG 1976	14	547.00 (419)	C6
8 APR 1976	11	538.00 (604)	C1
28 SEP 1976	13	533.00 (492)	C1
12 MAR 1976	18	521.00 (504)	C6

(C1) Dutch Hollow 6
(C4) Petersburg 2
(C5) Wilson Creek 5
(C6) Lawrenceburg 10
(C7) Elizabethtown 2
(C8) Kilby Road 0

24-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
25 NOV 1976	24	527.00 (495)	C6
26 NOV 1976	24	378.00 (360)	C6
13 APR 1976	24	277.00 (226)	C5
12 MAR 1976	24	248.00 (236)	C6
14 NOV 1976	24	229.00 (119)	C7
20 MAR 1976	24	226.00 (212)	C6
15 JUN 1976	24	218.00 (170)	C6
19 MAR 1976	24	212.00 (198)	C6
9 NOV 1976	24	203.00 (151)	C6
16 AUG 1976	24	195.00 (195)	C1
4 MAR 1976	24	192.00 (163)	C6
24 SEP 1976	24	184.00 (159)	C1
28 SEP 1976	24	169.00 (153)	C1
24 AUG 1976	24	159.00 (116)	C1
25 FEB 1976	24	159.00 ([illegible])	C6
29 MAR 1976	24	155.00 (138)	C5
10 DEC 1976	24	153.00 (118)	C6
5 MAY 1976	24	150.00 (113)	C6
12 APR 1976	24	149.00 (134)	C4
24 MAR 1976	24	149.00 (125)	C6
5 OCT 1976	24	148.00 (134)	C6
2 OCT 1976	24	148.00 (134)	C1
4 OCT 1976	24	148.00 (131)	C5
15 MAR 1976	24	148.00 (142)	C1
8 OCT 1976	24	146.00 (131)	C1

(C1) Dutch Hollow 7
(C4) Petersburg 1
(C5) Wilson Creek 3
(C6) Lawrenceburg 13
(C7) Elizabethtown 1
(C8) Kilby Road 0

Table B-3. Measured Episodes for Muskingum

3-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
3 OCT 1975	15	830.00(696)	1B
28 NOV 1975	16	695.00(639)	1C
28 JAN 1975	13	649.00(604)	1D
12 OCT 1975	14	591.00(552)	1A
23 JAN 1975	18	565.00(522)	1D
14 FEB 1975	14	554.00(526)	1B
5 MAY 1975	12	545.00(536)	1A
11 MAY 1975	13	519.00(608)	1A
25 MAY 1975	16	512.00(607)	1A
16 JUL 1975	17	510.00(428)	1B
29 APR 1975	15	508.00(464)	1B
9 AUG 1975	14	504.00(452)	1A
4 SEP 1975	16	502.00(461)	1A
29 JAN 1975	13	458.00(449)	1D
5 DEC 1975	14	453.00(372)	1C
15 APR 1975	13	452.00(385)	1A
10 APR 1975	13	449.00(384)	1A
11 JAN 1975	11	434.00(421)	1B
7 SEP 1975	17	434.00(361)	1B
28 JAN 1975	17	426.00(463)	1D
30 JAN 1975	17	422.00(405)	1C
6 APR 1975	12	420.00(410)	1A
24 JAN 1975	14	418.00(361)	1C
8 FEB 1975	15	416.00(366)	1C
21 APR 1975	15	387.00(363)	1A

(1A)	Beverly	10
(1B)	Hackney	6
(1C)	Rich Valley	5
(1D)	Caldwell	4

24-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
28 JAN 1975	24	328.00(304)	1D
3 OCT 1975	24	184.00(95)	1B
28 FEB 1975	24	166.00(115)	1A
29 JAN 1975	24	159.00(151)	1D
23 JAN 1975	24	156.00(129)	1D
27 FEB 1975	24	146.00(127)	1A
12 OCT 1975	24	145.00(132)	1A
11 MAY 1975	24	144.00(112)	1A
27 MAR 1975	24	137.00(7)	1A
3 FEB 1975	24	135.00(11)	1C
28 NOV 1975	24	130.00(98)	1C
6 APR 1975	24	130.00(113)	1A
28 MAR 1975	24	128.00(46)	1A
5 APR 1975	24	127.00(115)	1A
16 NOV 1975	24	125.00(61)	1B
11 MAR 1975	24	124.00(61)	1A
11 DEC 1975	24	124.00(77)	1C
18 NOV 1975	24	123.00(49)	1B
24 FEB 1975	24	122.00(117)	1A
21 JAN 1975	24	118.00(83)	1D
28 APR 1975	24	116.00(71)	1D
2 AUG 1975	24	116.00(51)	1C
13 APR 1975	24	115.00(105)	1A
10 APR 1975	24	115.00(67)	1A
30 JAN 1975	24	113.00(90)	1C

(1A)	Beverly	12
(1B)	Hackney	3
(1C)	Rich Valley	5
(1D)	Caldwell	5

Table B-3 (continued)

3-hr/ 1976

```
     DATE           HOUR   AVG. CONC.  SITE/RECEPTOR
12 SEP 1976          13    1319.00 (1300)     11
17 JUN 1976          14    1301.00 ([illegible])  12
14 APR 1976          14    1197.00 ([illegible])  12
11 MAR 1976          16     918.00 (913)      11
24 FEB 1976          14     915.00 (898)      13
 8 MAR 1976          12     833.00 ([illegible])  11
 8 MAR 1976          16     833.00 (826)      11
23 SEP 1976          13     827.00 ([illegible])  12
23 APR 1976          15     776.00 (761)      11
22 MAR 1976          11     773.00 ([illegible])  11
27 JUN 1976          18     770.00 ([illegible])  14
16 JUN 1976          12     738.00 (715)      12
13 SEP 1976          15     724.00 (687)      13
25 AUG 1976          14     690.00 (661)      13
15 NOV 1976          16     665.00 (643)      11
28 JAN 1976          13     656.00 ([illegible])  13
 4 MAR 1976          13     652.00 (646)      13
18 JAN 1976          14     632.00 (599)      11
30 AUG 1976          17     604.00 (548)      11
24 FEB 1976          17     596.00 (576)      13
 4 SEP 1976          15     586.00 ([illegible])  13
11 MAY 1976          12     585.00 (534)      12
12 APR 1976          16     581.00 (575)      11
30 APR 1976          16     578.00 (500)      13
26 JUN 1976          16     574.00 (505)      12
```

(11) Beverly 10
(12) Hackney 6
(13) Rich Valley 8
(14) Caldwell 1

24-hr/ 1976

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     DATE           HOUR   AVG. CONC.  SITE/RECEPTOR
17 JUN 1976          24     293.00 ([illegible])  12
24 FEB 1976          24     253.00 ([illegible])  13
14 APR 1976          24     252.00 ([illegible])  12
 8 MAR 1976          24     240.00 (223)      11
13 SEP 1976          24     207.00 (175)      13
23 SEP 1976          24     205.00 (184)      12
30 APR 1976          24     200.00 (181)      13
29 OCT 1976          24     189.00 (116)      13
23 APR 1976          24     187.00 (170)      11
12 SEP 1976          24     185.00 (119)      11
27 JUN 1976          24     183.00 (131)      14
 5 FEB 1976          24     178.00 ( 77)      11
15 APR 1976          24     166.00 ([illegible])  12
24 APR 1976          24     165.00 (141)      12
11 MAR 1976          24     164.00 (148)      11
 4 MAR 1976          24     161.00 (119)      13
 5 MAY 1976          24     158.00 (114)      13
25 FEB 1976          24     157.00 (105)      13
31 JAN 1976          24     152.00 ( 71)      13
24 MAR 1976          24     150.00 (112)      13
 4 SEP 1976          24     149.00 (136)      12
14 JUN 1976          24     147.00 (131)      12
20 APR 1976          24     146.00 ( 85)      13
16 JUN 1976          24     144.00 (131)      12
 6 MAY 1976          24     143.00 (100)      12
```

(11) Beverly 5
(12) Hackney 9
(13 Rich Valley 10
(14) Caldwell 1

Table B-4. Measured Episodes for Gavin-Kyger-Sporn

3-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
16 NOV 1975	16	789.00 (763)	75
8 AUG 1975	18	767.00 (756)	71
23 NOV 1975	22	763.00 (731)	7A
4 OCT 1975	17	749.00 (726)	71
8 APR 1975	17	741.00 (701)	72
29 JUL 1975	12	739.00 (724)	71
14 OCT 1975	13	724.00 (706)	76
3 JUN 1975	12	680.00 (676)	76
28 NOV 1975	15	677.00 (612)	75
9 JAN 1975	15	630.00 (613)	73
31 JUL 1975	13	627.00 (615)	73
9 MAY 1975	16	619.00 (574)	72
19 MAY 1975	10	618.00 (591)	73
3 OCT 1975	21	614.30 (598)	74
22 JUN 1975	12	611.00 (604)	73
18 NOV 1975	20	599.00 (548)	71
23 OCT 1975	13	574.00 (541)	76
9 APR 1975	13	572.00 (556)	71
17 NOV 1975	10	567.00 (537)	75
8 AUG 1975	15	566.00 (555)	71
30 JAN 1975	16	564.30 (587)	74
18 FEB 1975	14	548.00	73
21 OCT 1975	14	544.00 (527)	76
12 MAY 1975	13	542.00 (530)	73
26 SEP 1975	16	541.00 (534) (538)	71

(71) Kerr 7
(72) Henderson 2
(73) Lakin 6
(74) Wolfpen 2
(75) Mason 4
(76) New Haven 3
(77) Mt. Alto 0

(78) Five Points 0
(79) Dorcas 0
(7A) Coolville 1
(7B) Neptune 0

24-hr/ 1975

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
23 NOV 1975	24	241.00 (197)	7A
6 AUG 1975	24	238.00 (230)	71
16 NOV 1975	24	231.30 (197)	7A
4 OCT 1975	24	220.00 (213)	71
19 NOV 1975	24	217.00 (157)	74
18 NOV 1975	24	216.00 (177)	71
17 NOV 1975	24	214.00 (173)	7A
27 OCT 1975	24	203.00 (191)	74
8 APR 1975	24	203.00 (171)	72
3 OCT 1975	24	192.30 (176)	71
31 JAN 1975	24	190.00 (113)	72
9 JUN 1975	24	187.00 (179)	71
29 JUL 1975	24	186.00 (176)	71
1 FEB 1975	24	184.30 (101)	7A
8 MAY 1975	24	180.00 (149)	71
21 OCT 1975	24	166.30 (155)	75
28 NOV 1975	24	162.00 (119)	75
8 FEB 1975	24	158.00 (148)	75
20 FEB 1975	24	156.00 (150)	79
7 MAY 1975	24	153.00 (129)	71
24 NOV 1975	24	150.00 (73)	76
30 JAN 1975	24	148.00 (126)	74
2 FEB 1975	24	148.00 (67)	74
19 SEP 1975	24	145.30 (142)	7A
30 SEP 1975	24	144.00 (127)	7A

(71) Kerr 8
(72) Henderson 2
(73) Lakin 0
(74) Wolfpen 4
(75) Mason 3
(76) New Haven 1
(77) Mt. Alto 0

(78) Five Pts. 0
(79) Dorcas 1
(7A) Coolville 6
(7B) Neptune 0

Table B-4 (continued)

3-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
28 MAR 1976	17	1079.00 (1067)	71
17 JUN 1976	17	1067.00 (1027)	71
27 FEB 1976	14	983.00 (934)	73
13 APR 1976	16	920.00 (873)	76
13 APR 1976	10	881.00 (838)	76
9 MAY 1976	18	871.00 (832)	76
11 MAR 1976	18	840.00 (821)	71
13 APR 1976	22	793.00 (721)	76
14 APR 1976	2	788.00 (733)	74
5 APR 1976	15	783.00 (764)	73
28 OCT 1976	16	741.00 (707)	75
19 OCT 1976	13	723.00 (711)	74
21 SEP 1976	12	716.00 (713)	77
20 OCT 1976	14	708.00 (636)	73
20 OCT 1976	17	704.00 (651)	74
11 MAR 1976	14	698.00 (661)	71
12 SEP 1976	17	692.00 (676)	73
28 FEB 1976	18	679.00 (663)	73
14 APR 1976	9	671.00 (631)	74
18 OCT 1976	13	663.00 (636)	78
24 DEC 1976	18	646.00 (622)	74
30 APR 1976	18	639.00 (619)	74
12 OCT 1976	18	629.00 (617)	73
5 OCT 1976	14	606.00 (577)	73
28 MAR 1976	14	604.30 (595)	71

(71) Kerr 5
(72) Henderson 0
(73) Lakin 7
(74) Wolpen 6
(75) Mason 1
(76) New Haven 4
(77) Mt. Alto 1

(78) Five Points 1
(79) Dorcas 0
(7A) Coolville 0
(7B) Neptune 0

24-hr/ 1976

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
13 APR 1976	24	436.00 (346)	76
14 APR 1976	24	282.00 (235)	76
11 MAR 1976	24	266.00 (242)	71
28 MAR 1976	24	237.00 (231)	71
9 MAY 1976	24	232.00 (212)	76
17 JUN 1976	24	197.00 (191)	71
30 APR 1976	24	190.00 (150)	75
24 FEB 1976	24	189.00 (183)	75
18 OCT 1976	24	188.00 (167)	71
19 OCT 1976	24	184.00 (165)	74
29 OCT 1976	24	177.00 (144)	74
17 NOV 1976	24	173.00 (131)	71
15 FEB 1976	24	171.00 (153)	75
11 AUG 1976	24	170.00 (152)	74
8 FEB 1976	24	167.00 (73)	7A
27 FEB 1976	24	167.00 (153)	73
28 FEB 1976	24	159.00 (125)	78
5 APR 1976	24	150.00 (126)	73
13 SEP 1976	24	148.00 (133)	75
23 AUG 1976	24	148.00 (107)	71
19 DEC 1976	24	146.00 (135)	78
8 JAN 1976	24	146.00 (86)	7A
25 SEP 1976	24	145.00 (116)	71
3 JUL 1976	24	144.00 (120)	7A
20 MAY 1976	24	143.00 (115)	76

(71) Kerr 7
(72) Henderson 0
(73) Lakin 2
(74) Wolfpen 3
(75) Mason 4
(76) New Haven 4
(77) Mt. Alto 0

(78) Five Pts. 2
(79) Dorcas 0
(7A) Coolville 3
(7B) Neptune 0

Table B-5(a). CRSTER (Turner) Calculated Episodes for Clifty Creek 1975

3-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
23	JUL	1975	[illegible]	1818.97	40
31	JUL	1975	[illegible]	1482.75	49
7	JUL	1975	[illegible]	1448.41	61
[illegible]	JUL	1975	[illegible]	[illegible]	61
15	JUL	1975	[illegible]	[illegible]	69
25	MAY	1975	6	1278.16	68
10	FEB	1975	9	1281.50	212
26	APR	1975	[illegible]	1276.97	247
12	OCT	1975	[illegible]	1214.48	211
31	JUL	1975	4	1141.83	42
17	JUN	1975	[illegible]	1140.97	198
25	JUL	1975	10	1098.60	204
27	JUN	1975	[illegible]	1062.39	169
26	AUG	1975	9	1028.97	193
24	MAY	1975	[illegible]	1004.28	187
6	SEP	1975	[illegible]	1004.85	195
18	AUG	1975	[illegible]	987.37	66
13	OCT	1975	[illegible]	979.93	193
6	MAR	1975	[illegible]	970.21	197
2	JUN	1975	[illegible]	964.26	63
14	JUL	1975	[illegible]	939.21	219
13	JUL	1975	[illegible]	935.54	173
29	AUG	1975	[illegible]	931.68	213
[illegible]	AUG	1975	[illegible]	930.33	223
19	MAY	1975	[illegible]	927.80	163

24-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
21	JUL	1975	24	245.55	40
26	APR	1975	24	235.32	252
1	JUL	1975	24	226.63	236
22	JUN	1975	24	226.12	167
24	MAY	1975	24	222.75	187
31	JUL	1975	24	206.17	265
23	JUL	1975	24	201.76	206
16	OCT	1975	24	196.75	290
1	MAR	1975	24	190.70	325
5	JUL	1975	24	186.24	59
20	APR	1975	24	184.27	217
21	OCT	1975	24	181.17	293
7	JUL	1975	24	181.05	61
5	JUL	1975	24	180.73	194
11	AUG	1975	24	177.14	221
4	JUL	1975	24	173.73	61
16	JUL	1975	24	166.73	69
19	AUG	1975	24	166.17	172
21	MAY	1975	24	[illegible]	64
11	JUN	1975	24	164.25	324
27	JUL	1975	24	162.80	281
13	MAY	1975	24	[illegible]	204
13	FEB	1975	24	157.71	212
12	OCT	1975	24	157.41	211
13	AUG	1975	24	157.34	256

1-36 1km (0)[a]
37-72 1.5km (9)
73-108 2km (0)
109-144 2.5km (0)
145-180 3.06km (4)
181-216 4.51 km (9)
217-252 7.40 km (3)
253-288 8.05 km (0)
289-324 11.58km (0)
325-360 14.96km (0)

3-hr/ Selected Receptors

1-36 (0)
37-72 (6)
73-108 (0)
109-144 (0)
145-180 (2)
181-216 (7)
217-252 (3)
253-288 (3)
289-324 (2)
325-360 (2)

24-hr/ Selected Receptors

Table B-5(a) continued

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
17	NOV	1975	13	838.91	290
22	JUL	1975	14	786.69	222
13	APR	1975	16	767.38	161
2	NOV	1975	18	741.86	182
5	JUL	1975	15	724.70	222
24	MAR	1975	19	700.97	222
16	APR	1975	19	683.47	182
19	MAY	1975	13	669.12	182
1	AUG	1975	13	659.26	222
19	NOV	1975	14	633.75	290
23	JUL	1975	13	610.42	182
11	MAY	1975	13	596.60	182
6	MAR	1975	12	594.18	182
20	MAY	1975	11	571.55	290
25	MAY	1975	14	565.01	182
16	NOV	1975	6	564.73	328
14	DEC	1975	21	544.39	290
13	AUG	1975	14	540.25	328
5	MAR	1975	13	536.64	290
13	FEB	1975	14	528.93	161
20	FEB	1975	12	522.50	222
29	APR	1975	12	519.01	290
13	OCT	1975	12	491.64	182
25	FEB	1975	16	487.29	222
14	DEC	1975	24	482.90	290

(328)Bacon Ridge 2
(222)Rykers Ridge 6
(182)N. Madison 8
(290)Hebron Church 7
(161)Liberty Ridge 2
(262) Canip Creek 0

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
16	OCT	1975	24	186.75	290
21	OCT	1975	24	181.17	290
21	JAN	1975	24	166.75	328
25	AUG	1975	24	146.93	328
19	JUN	1975	24	141.69	182
10	MAY	1975	24	139.34	182
3	AUG	1975	24	136.52	328
1	MAY	1975	24	123.39	182
16	MAY	1975	24	122.86	222
27	JUN	1975	24	121.37	222
17	NOV	1975	24	121.19	290
25	FEB	1975	24	121.06	222
29	APR	1975	24	117.58	182
18	APR	1975	24	116.34	290
6	NOV	1975	24	114.83	328
3	DEC	1975	24	114.64	290
5	DEC	1975	24	113.55	290
16	JUN	1975	24	112.62	290
26	FEB	1975	24	101.33	328
5	JUN	1975	24	100.66	222
5	MAR	1975	24	99.52	290
6	JUN	1975	24	98.94	290
11	APR	1975	24	97.94	161
14	MAR	1975	24	94.59	222
9	NOV	1975	24	93.73	182

(328)Bacon Ridge 5
(222)Rykers Ridge 5
(182)N. Madison 5
(290)Hebron Church 9
(161)Liberty Ridge 1
(262) Canip Creek 0

a Number of cases

Table B-5(b). CRSTER (Turner) Calculated Episodes For Clifty Creek 1976

3-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
19	JUL	1976	13	3306.91	70
28	APR	1976	14	2020.55	46
19	AUG	1976	15	1763.12	70
26	JUN	1976	14	1622.36	65
5	JUL	1976	13	1518.50	59
14	SEP	1976	14	1373.06	48
12	APR	1976	12	1335.47	169
11	MAY	1976	14	1220.03	144
21	AUG	1976	14	1135.61	58
13	JUL	1976	14	1129.11	49
27	JUN	1976	16	1126.66	48
22	MAY	1976	13	1074.69	60
30	JUL	1976	16	1057.17	192
22	MAY	1976	10	1050.21	204
27	APR	1976	15	1047.58	196
18	AUG	1976	12	1034.15	205
12	JUN	1976	13	1017.81	148
14	JUL	1976	15	997.17	75
7	JUN	1976	12	989.84	158
12	AUG	1976	14	988.84	155
25	JUL	1976	15	986.48	171
26	JUN	1976	11	982.58	64
23	APR	1976	14	978.04	147
7	SEP	1976	14	960.68	246
19	AUG	1976	13	940.20	204

1-36 1km (0)[a]
37-72 1.5km (11)
73-108 2km (1)
109-144 2.5km (1)
145-180 3.06km (5)

181-216 4.51km (6)
217-252 7.40km (1)
253-288 8.05km (0)
289-324 11.58km(0)
325-360 14.96km(0)

24-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
19	JUL	1976	24	413.36	70
25	JUL	1976	24	267.49	206
26	JUN	1976	24	259.60	65
28	APR	1976	24	252.57	46
5	JUL	1976	24	251.33	234
19	AUG	1976	24	238.28	240
18	AUG	1976	24	235.81	205
14	APR	1976	24	230.76	181
4	JUN	1976	24	230.67	206
27	APR	1976	24	227.04	196
13	AUG	1976	24	220.39	70
23	JUL	1976	24	219.40	184
25	NOV	1976	24	217.42	325
19	MAR	1976	24	211.37	290
9	JUL	1976	24	207.07	208
12	APR	1976	24	199.75	335
26	NOV	1976	24	199.72	325
7	JUL	1976	24	195.78	219
22	MAY	1976	24	188.19	204
23	APR	1976	24	187.64	182
12	AUG	1976	24	182.65	221
9	AUG	1976	24	176.60	200
2	MAR	1976	24	173.85	290
14	SEP	1976	24	171.63	48
7	JUN	1976	24	168.93	158

1-36 (0)
37-72 (5)
73-108 (0)
109-144 (0)
145-180 (1)

181-216 (11)
217-252 (4)
253-288 (0)
289-324 (2)
325-360 (2)

Table B-5(b) continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
23 APR 1976	14	891.12	182
14 APR 1976	15	879.09	182
29 JUN 1976	15	841.35	182
18 APR 1976	13	775.12	182
1 JUN 1976	16	759.61	222
1 AUG 1976	16	726.37	222
8 MAY 1976	16	699.02	161
23 APR 1976	16	673.55	262
5 MAY 1976	15	662.78	182
29 JUL 1976	17	658.11	222
14 JUL 1976	14	641.65	328
2 MAY 1976	15	637.96	182
29 JAN 1976	6	592.22	328
12 JUN 1976	16	587.98	182
4 MAY 1976	9	584.37	290
10 APR 1976	13	583.42	182
11 AUG 1976	13	562.92	182
9 FEB 1976	13	557.93	182
16 MAY 1976	13	557.68	290
29 APR 1976	15	546.04	161
4 AUG 1976	14	545.05	222
13 JUN 1976	13	544.93	182
9 SEP 1976	13	543.54	222
7 JUL 1976	9	540.73	290
11 AUG 1976	18	533.77	222

(328)Bacon Ridge 2
(222)Rykers Ridge 6
(182)N. Madison 11
(290)Hebron Church 3
(161) Liberty Ridge 2
(262)Canip Creek 1

24-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
19 MAR 1976	24	211.57	290
14 APR 1976	24	198.58	182
23 APR 1976	24	187.64	182
2 MAR 1976	24	173.85	290
6 MAR 1976	24	162.58	290
25 FEB 1976	24	158.69	290
19 APR 1976	24	156.19	182
14 JUL 1976	24	152.98	328
10 JUL 1976	24	149.98	328
29 JUN 1976	24	144.15	182
5 MAY 1976	24	139.58	290
1 MAR 1976	24	130.33	182
13 FEB 1976	24	129.03	328
11 JUN 1976	24	122.33	222
17 NOV 1976	24	118.52	328
13 DEC 1976	24	117.29	290
27 APR 1976	24	114.41	328
25 NOV 1976	24	112.83	290
12 JUN 1976	24	112.08	182
24 FEB 1976	24	109.76	290
7 JUL 1976	24	109.36	328
23 JUL 1976	24	105.52	328
24 MAR 1976	24	103.33	290
6 MAY 1976	24	102.31	290
13 MAY 1976	24	96.69	182

(328)Bacon Ridge 7
(222)Rykers Ridge 1
(182)N. Madison 7
(290)Hebron Church 10
(161)Liberty Ridge 0
(262)Canip Creek 0

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[a] Number of cases

Table B-5(c). CRSTER (Irwin) Calculated Episodes for Clifty Creek 1975

3-hr/ Full Set of Receptors

```
    DATE              HOUR  AVG. CONC.  SITE/RECEPTOR
11  AUG  1975          16    1790.50         77
22  JUN  1975          14    1786.75         41
 8  JUL  1975          16    1782.04         86
20  MAY  1975          17    1650.50         71
 3  JUL  1975          16    1619.67         49
14  JUL  1975          15    1574.04        111
13  SEP  1975          16    1565.09         87
29  APR  1975          17    1521.78         73
19  MAY  1975          14    1520.93         39
13  OCT  1975          15    1479.39         76
30  JUL  1975          15    1420.96         98
12  JUN  1975          13    1399.36         42
27  MAY  1975          16    1377.77         88
25  MAY  1975          16    1372.66         39
 7  AUG  1975          14    1336.79         98
11  MAY  1975          14    1298.43          2
20  MAY  1975          13    1294.08         73
 2  NOV  1975          16    1292.17         74
21  AUG  1975          14    1288.13        113
18  JUN  1975          18    1287.85         37
 8  JUL  1975          13    1265.78        122
13  JUN  1975          10    1262.05        151
 8  APR  1975          12    1260.09        170
20  JUN  1975          18    1244.94         88
21  JUL  1975          18    1238.36        157
```

1-36 1 km (1)
37-72 1.5 km (7)
73-108 2 km (11)
109-144 2.5km (3)
145-180 3.06 km (3)

181-216 4.51km (0)
217-252 7.40km (0)
253-288 8.05km (0)
289-324 11.58km (0)
325-360 14.96km (0)

24-hr/ Full Set of Receptors

```
    DATE              HOUR  AVG. CONC.  SITE/RECEPTOR
21  OCT  1975          24     410.44        230
22  JUN  1975          24     403.74         41
 8  JUL  1975          24     369.80        122
21  MAR  1975          24     361.67        181
14  DEC  1975          24     338.26        182
13  SEP  1975          24     335.27         87
30  JUL  1975          24     299.39        136
24  MAY  1975          24     298.94         78
20  MAY  1975          24     298.81         72
 1  JUL  1975          24     297.72        133
24  FEB  1975          24     296.83        148
13  JUN  1975          24     289.33         79
21  JUL  1975          24     282.31        121
 8  APR  1975          24     280.49        242
14  JUL  1975          24     278.06         75
14  SEP  1975          24     274.14        134
30  NOV  1975          24     270.92        145
 5  DEC  1975          24     270.34        210
20  JUN  1975          24     269.15         51
25  FEB  1975          24     268.28        156
29  APR  1975          24     266.79         73
26  APR  1975          24     265.62        170
 3  APR  1975          24     264.87        156
19  MAY  1975          24     261.80         38
21  FEB  1975          24     256.60        232
```

1-36 (0)
37-72 (4)
73-108 (5)
109-144 (5)
145-180 (5)

181-216 (3)
217-252 (3)
253-288 (0)
289-324 (0)
325-360 (0)

Table B-5(c). Continued

3-hr Selected Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
13 APR 1975	16	967.96	161
14 DEC 1975	21	950.51	182
4 DEC 1975	22	944.94	182
16 NOV 1975	6	901.08	328
15 DEC 1975	1	876.73	182
21 OCT 1975	2	843.53	182
16 APR 1976	14	838.39	182
5 MAR 1975	13	827.77	182
19 MAY 1975	12	791.57	182
5 DEC 1975	3	764.90	290
13 FEB 1975	12	732.33	161
24 MAR 1976	19	714.66	222
8 MAR 1975	15	710.40	182
19 NOV 1975	15	709.80	182
13 OCT 1975	12	697.04	182
21 OCT 1975	23	694.44	182
6 JUL 1975	13	692.32	182
2 NOV 1975	16	681.74	182
20 NOV 1975	20	679.93	222
5 MAY 1975	18	671.70	182
26 FEB 1975	6	668.03	222
25 AUG 1975	4	659.60	328
14 JUL 1975	16	653.03	182
14 JUN 1975	3	646.19	182
18 APR 1976	18	643.63	182

(328) Bacon Ridge (2)
(222) Rykers Ridge (3)
(182) North Madison (17)
(290) Hebron Church (1)
(161) Liberty Ridge (2)
(262) Canip Creek (0)

24-hr/ Selected Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 OCT 1975	24	366.20	182
14 DEC 1975	24	338.26	182
5 DEC 1975	24	246.64	290
18 APR 1976	24	218.86	182
14 JUN 1975	24	197.67	182
4 DEC 1975	24	189.17	290
25 AUG 1975	24	188.80	328
18 JUN 1975	24	179.22	182
16 NOV 1975	24	177.31	328
13 DEC 1975	24	175.01	290
30 NOV 1975	24	174.33	182
5 MAR 1976	24	168.10	182
27 NOV 1975	24	165.12	222
19 MAY 1975	24	159.03	182
15 JUN 1975	24	156.79	182
25 FEB 1976	24	150.84	222
16 APR 1976	24	150.64	182
14 JUL 1975	24	149.23	182
19 APR 1976	24	145.38	222
13 FEB 1975	24	140.46	161
13 APR 1975	24	136.07	161
21 NOV 1975	24	131.34	222
4 JUN 1976	24	129.32	182
24 AUG 1975	24	124.81	290
24 MAY 1976	24	121.47	222

(328) Bacon Ridge (2)
(222) Rykers Ridge (5)
(182) North Madison (12)
(290) Hebron Church (4)
(161) Liberty Ridge (2)
(262) Canip Creek (0)

Table B-5(d). CRSTER (Irwin) Calculated Episodes for Clifty Creek 1976

3-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
13 MAY 1976	14	2038.99	36
27 APR 1976	15	1876.58	88
12 AUG 1976	14	1865.65	77
11 JUN 1976	14	1802.41	42
20 JUL 1976	18	1644.05	76
29 JUN 1976	15	1563.73	74
25 JUL 1976	15	1549.19	63
14 APR 1976	16	1529.32	38
10 JUN 1976	15	1514.14	77
14 JUN 1976	14	1469.71	39
4 JUN 1976	13	1452.78	98
18 AUG 1976	13	1446.22	133
21 JUL 1976	14	1420.86	113
5 JUN 1976	14	1411.03	98
23 JUN 1976	16	1408.50	106
20 JUL 1976	14	1397.96	112
27 AUG 1976	16	1392.09	109
5 MAY 1976	14	1388.38	38
1 AUG 1976	16	1386.23	127
9 AUG 1976	17	1368.88	163
13 JUN 1976	13	1357.33	37
18 APR 1976	13	1326.18	38
24 APR 1976	14	1321.92	37
4 JUN 1976	10	1301.42	134
14 DEC 1976	21	1282.14	210

1-36 1km (1)
37-72 1.5km (8)
73-108 2km (8)
109-144 2.5km (6)
145-180 3.06km (1)
181-216 4.51km (0)
217-252 7.40km (1)
253-288 8.05km (0)
289-324 11.58km (0)
325-360 14.96km (0)

24-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
25 JUL 1976	24	470.32	98
25 NOV 1976	24	431.52	217
20 JUL 1976	24	395.27	76
27 APR 1976	24	390.75	124
12 AUG 1976	24	385.56	77
4 JUN 1976	24	371.75	134
9 AUG 1976	24	361.50	163
18 AUG 1976	24	355.68	133
16 FEB 1976	24	351.52	183
12 JUN 1976	24	341.45	75
14 APR 1976	24	339.91	74
23 JUN 1976	24	330.73	69
19 MAR 1976	24	325.75	182
10 JUN 1976	24	323.17	77
4 MAR 1976	24	318.80	218
26 NOV 1976	24	317.66	101
11 JUN 1976	24	315.92	42
5 JUN 1976	24	286.59	98
7 JUL 1976	24	280.53	147
14 DEC 1976	24	279.22	218
18 APR 1976	24	273.42	74
2 JUL 1976	24	272.28	112
24 FEB 1976	24	270.10	218
1 AUG 1976	24	269.02	127
5 MAY 1976	24	264.89	217

1-36 (0)
37-72 (2)
73-108 (8)
109-244 (5)
145-180 (2)
181-216 (3)
217-252 (5)
253-288 (0)
289-324 (0)
325-360 (0)

Table B-5(d) continued

3-hr/Selected Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
14 DEC 1976	21	1062.90	290
29 JUN 1976	15	963.77	182
10 MAY 1976	12	948.06	182
14 OCT 1976	16	894.73	182
16 MAY 1976	13	892.13	182
23 APR 1976	18	868.29	182
14 JUL 1976	24	863.09	182
15 FEB 1976	16	854.62	328
24 JAN 1976	6	828.46	222
9 MAR 1976	22	818.77	328
14 APR 1976	15	797.72	182
8 MAY 1976	16	790.20	182
19 JUL 1976	18	788.06	161
18 APR 1976	12	781.64	182
13 JUN 1976	13	771.32	182
10 APR 1976	13	769.91	182
7 JUN 1976	16	769.32	182
18 FEB 1976	13	763.37	161
23 FEB 1976	22	725.19	182
19 MAR 1976	8	722.68	182
27 FEB 1976	13	708.61	182
21 MAY 1976	2	680.27	328
4 AUG 1976	17	677.84	182
6 NOV 1976	1	676.49	290
4 SEP 1976	14	675.87	222

(328) Bacon Ridge (3)
(222) Rykers Ridge (2)
(182) North Madison (16)
(290) Hebron Church (2)
(161) Liberty Ridge (2)
(262) Canip Creek (0)

24-hr/ Selected Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
10 MAR 1976	24	325.75	182
9 MAR 1976	24	298.63	182
14 DEC 1976	24	243.46	290
8 MAY 1976	24	241.63	182
25 FEB 1976	24	234.67	182
2 MAR 1976	24	234.28	182
24 FEB 1976	24	231.46	182
1 MAR 1976	24	221.65	182
26 NOV 1976	24	216.51	182
14 APR 1976	24	208.77	182
13 MAY 1976	24	201.50	182
10 DEC 1976	24	197.04	182
18 APR 1976	24	185.35	182
26 MAR 1976	24	182.61	182
23 APR 1976	24	178.91	182
14 JUL 1976	24	167.17	182
8 MAY 1976	24	166.13	328
16 FEB 1976	24	157.94	161
29 JUN 1976	24	157.39	182
10 APR 1976	24	151.41	182
11 JUL 1976	24	149.44	182
26 JAN 1976	24	149.36	222
19 JUL 1976	24	148.65	328
6 MAY 1976	24	145.38	182
23 FEB 1976	24	142.25	182

(328) Bacon Ridge (2)
(222) Rykers Ridge (1)
(182) North Madison (20)
(290) Hebron Church (1)
(161) Liberty Ridge (1)
(262) Canip Creek (0)

Table B-6(a). CRSTER (Turner) Calculated Episodes for Tanners Creek 1975

3-hr/ Full Set of Receptors

```
        DATE              HOUR   AVG. CONC.   SITE/RECEPTOR
  7  AUG  1975              1     4667.92          237
  1  SEP  1975              7     4636.01          226
  7  AUG  1975              5     4503.86          237
 26  OCT  1975              8     4152.63          237
 26  FEB  1975             24     3916.66          226
 17  DEC  1975              4     3821.09          298
 21  FEB  1975             24     3630.85          177
 13  JAN  1975             21     3558.67          226
 16  JAN  1975             23     3550.56          290
 20  JAN  1975             22     3487.34          360
 10  SEP  1975              1     3471.69          302
 21  SEP  1975             22     3147.49          297
  8  SEP  1975             24     3098.92          237
 11  NOV  1975             20     3096.09          177
 16  APR  1975              4     2959.85          226
 23  OCT  1975             20     2901.26          358
 13  FEB  1975             23     2850.89          237
 20  AUG  1975              8     2825.63          238
 20  AUG  1975             23     2727.79          318
 22  DEC  1975             23     2671.86          298
 14  NOV  1975             22     2638.90          297
 17  MAR  1975             22     2636.71          360
  9  MAR  1975             22     2603.54          319
  4  MAR  1975              5     2577.53          227
 20  NOV  1975              1     2555.23          250
```

1-36 1km (0)
37-72 1.45km (0)
73-108 2km (0)
109-144 2.5km (0)
145-180 3.70km (2)

181-216 3.86km (0)
217-252 5.79km (11)
253-288 9.81km (0)
289-324 12km (7)
325-360 16.09km (5)

24-hr/ Full Set of Receptors

```
        DATE              HOUR   AVG. CONC.   SITE/RECEPTOR
 12  JAN  1975             24      913.13          226
  7  AUG  1975             24      861.47          237
 21  FEB  1975             24      796.21          177
  3  APR  1975             24      775.02          121
  6  NOV  1975             24      685.10          359
 26  MAR  1975             24      653.46          226
 10  MAY  1975             24      647.53          237
  1  SEP  1975             24      624.27          226
  6  AUG  1975             24      601.80          237
 27  OCT  1975             24      596.62          359
 21  SEP  1975             24      595.15          297
 26  FEB  1975             24      579.08          228
 20  AUG  1975             24      568.43          238
 24  SEP  1975             24      552.70          237
 26  OCT  1975             24      552.11          237
  3  MAR  1975             24      551.53          301
 19  NOV  1975             24      550.06          356
 24  DEC  1975             24      538.60          353
 28  JAN  1975             24      535.41          189
  9  SEP  1975             24      532.28          238
  2  FEB  1975             24      527.09          236
 20  JAN  1975             24      497.95          360
 17  DEC  1975             24      496.53          298
 11  NOV  1975             24      487.67          177
 27  FEB  1975             24      468.00          226
```

1-36 (0)
37-72 (0)
73-108 (0)
109-144 (1)
145-180 (2)

181-216 (1)
217-252 (13)
253-288 (0)
289-324 (3)
325-360 (5)

Table B-6(a). Continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 AUG 1976	8	2825.63	238
21 FEB 1975	24	2678.84	213
11 NOV 1975	20	2240.64	213
7 OCT 1976	3	1871.58	238
21 FEB 1975	21	1487.89	213
8 DEC 1976	6	1429.16	238
9 SEP 1975	3	1396.03	238
6 JAN 1975	3	1386.20	213
30 OCT 1976	10	1384.18	238
9 MAY 1975	23	1267.89	238
9 SEP 1976	14	1233.73	238
7 AUG 1975	10	1188.35	238
14 AUG 1975	6	1143.07	238
17 OCT 1975	11	1119.97	238
22 DEC 1975	2	1100.93	238
9 SEP 1975	17	1058.99	238
7 DEC 1976	1	1039.63	238
20 OCT 1976	12	982.46	238
1 JUL 1976	6	982.07	238
2 FEB 1976	17	973.72	238
4 SEP 1975	17	967.92	238
9 MAY 1975	9	960.28	236
3 DEC 1975	24	939.57	213
31 JAN 1975	10	937.52	238
27 AUG 1975	13	892.60	238

(238) Dutch Hollow 20
(165) Petersburg 0
(213) Wilson Creek 5
(38) Lawrenceburg 0
(255) Elizabethtown 0
(326) Kilby Road 0

24-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 FEB 1975	24	597.71	213
26 AUG 1976	24	568.43	238
5 SEP 1975	24	532.[illegible]	238
2 FEB 1976	24	527.09	238
5 MAY 1976	24	482.69	238
7 AUG 1976	24	423.41	238
11 NOV 1976	24	371.64	213
24 SEP 1976	24	294.99	238
30 OCT 1976	24	290.70	238
17 OCT 1975	24	274.30	238
7 OCT 1976	24	260.27	238
10 MAY 1975	24	233.58	238
23 SEP 1975	24	225.23	238
1 JUL 1975	24	210.62	238
10 APR 1976	24	206.92	238
4 SEP 1975	24	193.34	238
14 MAY 1975	24	188.69	213
8 DEC 1975	24	180.84	238
24 FEB 1976	24	178.56	255
6 JAN 1976	24	173.69	213
21 OCT 1975	24	167.16	255
16 MAY 1976	24	165.64	238
14 AUG 1975	24	160.65	238
2 SEP 1976	24	156.39	238
25 JUL 1975	24	152.15	238

(238) Dutch Hollow 19
(165) Petersburg 0
(213) Wilson Creek 4
(38) Lawrenceburg 0
(255) Elizabethtown 1
(326) Kilby Road 0

Table B-6(b). CRSTER (Turner) Calculated Episodes for Tanners Creek 1976

3-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
30 APR 1976	24	4967.79	359
8 NOV 1976	6	3561.51	227
24 AUG 1976	22	3065.59	362
12 SEP 1976	21	3035.59	[illegible]
9 JUL 1976	23	3028.66	[illegible]
23 NOV 1976	7	2777.85	187
11 AUG 1976	7	2618.34	249
14 JUL 1976	6	2601.76	297
28 MAY 1976	2	2599.20	248
21 JUL 1976	24	2586.43	359
21 AUG 1976	1	2563.88	353
30 APR 1976	21	2527.85	359
4 OCT 1976	20	2497.15	249
16 APR 1976	22	2453.97	289
19 APR 1976	23	2356.89	297
27 APR 1976	21	2265.73	356
2 AUG 1976	21	2244.22	271
14 MAR 1976	7	2204.43	286
3 APR 1976	6	2191.57	359
5 OCT 1976	1	2179.31	177
22 JUN 1976	2	2171.82	359
22 DEC 1976	3	2171.60	289
16 JUN 1976	3	2097.49	248
16 JUL 1976	23	2085.04	196
2 AUG 1976	24	2074.66	237

1-36 1km (0)[a]
37-72 1.45km (0)
73-108 2km (0)
109-144 2.5km (0)
145-180 3.70km (1)
181-216 3.86km (2)
217-252 5.79km (8)
253-288 9.81km (1)
289-324 12km (5)
325-360 16.09km (8)

24-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
30 APR 1976	24	947.54	359
8 NOV 1976	24	741.68	227
2 AUG 1976	24	581.04	237
12 SEP 1976	24	499.54	249
4 OCT 1976	24	489.24	177
21 DEC 1976	24	486.24	120
17 AUG 1976	24	474.87	238
24 AUG 1976	24	459.85	239
16 APR 1976	24	457.55	289
23 NOV 1976	24	453.65	187
17 APR 1976	24	451.66	289
16 MAR 1976	24	424.15	156
25 NOV 1976	24	423.90	254
30 JUN 1976	24	423.06	226
8 SEP 1976	24	415.26	344
15 MAR 1976	24	411.28	238
14 JUL 1976	24	408.50	297
3 MAY 1976	24	406.61	156
2 AUG 1976	24	[illegible]	237
16 AUG 1976	24	393.27	239
9 JUL 1976	24	392.48	249
15 JUN 1976	24	387.74	254
14 MAR 1976	24	383.39	289
18 NOV 1976	24	380.66	226
22 DEC 1976	24	374.38	289

1-36 (0)
37-72 (0)
73-108 (0)
109-144 (1)
145-180 (3)
181-216 (1)
217-252 (11)
253-288 (2)
289-324 (5)
325-360 (2)

Table B-6(b) continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
24 AUG 1976	6	1930.05	238
7 AUG 1976	3	1868.13	238
1 OCT 1976	1	1842.15	213
6 OCT 1976	20	1820.07	213
12 SEP 1976	21	1455.14	213
27 OCT 1976	6	1399.68	238
11 AUG 1976	8	1353.18	213
22 MAY 1976	24	1330.65	238
26 MAY 1976	4	1300.19	238
18 OCT 1976	1	1254.80	238
17 AUG 1976	20	1231.00	238
9 JUL 1976	23	1220.22	213
19 AUG 1976	10	1218.80	238
21 AUG 1976	14	1190.27	238
9 AUG 1976	22	1171.01	238
26 AUG 1976	12	1135.65	238
17 MAR 1976	13	1108.00	238
26 SEP 1976	1	1102.32	238
17 AUG 1976	10	1099.78	238
20 APR 1976	6	1089.37	238
18 JUL 1976	7	1057.02	213
24 JUL 1976	21	1049.04	238
12 JAN 1976	21	1003.05	213
6 JUL 1976	8	998.68	238
17 AUG 1976	15	973.25	238

(238) Dutch Hollow 18
(165) Petersburg 0
(213) Wilson Creek 7
(38) Lawrenceburg 0
(255) Elizabethtown 0
(326) Kilby Road 0

24-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
17 AUG 1976	24	476.07	238
24 AUG 1976	24	450.08	238
11 MAR 1976	24	411.25	238
11 AUG 1976	24	393.27	238
6 OCT 1976	24	388.40	213
3 AUG 1976	24	342.94	238
21 AUG 1976	24	330.01	238
19 AUG 1976	24	325.41	238
15 SEP 1976	24	305.19	213
27 OCT 1976	24	303.90	238
26 MAY 1976	24	282.60	238
10 AUG 1976	24	273.90	238
7 AUG 1976	24	252.91	238
22 MAY 1976	24	236.30	238
3 JUN 1976	24	224.41	238
26 SEP 1976	24	219.36	238
15 NOV 1976	24	211.80	238
9 AUG 1976	24	208.74	238
22 NOV 1976	24	206.93	326
15 JUN 1976	24	204.53	326
20 MAY 1976	24	202.87	238
28 SEP 1976	24	200.51	238
9 APR 1976	24	198.56	238
11 APR 1976	24	194.17	238
1 AUG 1976	24	183.20	238

(238) Dutch Hollow 21
(165) Petersburg 0
(213) Wilson Creek 2
(38) Lawrenceburg 0
(255) Elizabethtown 0
(326) Kilby Road 2

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[a] Number of Cases

Table B-6(c). CRSTER (Irwin) Calculated Episodes for Tanners Creek 1975

3-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
7	AUG	1975	1	5441.20	237
1	SEP	1975	6	5121.64	236
16	JAN	1975	19	4957.69	151
7	AUG	1975	5	4926.43	237
21	FEB	1975	24	4731.36	177
26	OCT	1975	8	4620.43	237
11	NOV	1975	19	4488.71	177
13	JAN	1975	21	4233.30	226
19	MAR	1975	23	4210.58	151
26	FEB	1975	24	4182.84	256
5	JAN	1975	23	3768.26	195
8	SEP	1975	24	3718.19	237
17	DEC	1975	4	3697.47	226
29	JAN	1975	22	3636.00	360
9	MAR	1975	23	3604.57	175
4	MAR	1975	5	3579.19	155
16	APR	1975	4	3567.29	226
3	DEC	1975	24	3526.28	212
7	FEB	1975	4	3464.65	155
28	FEB	1975	21	3419.99	121
25	NOV	1975	1	3384.62	186
29	AUG	1975	8	3288.96	238
17	MAR	1975	22	3259.16	360
16	JAN	1975	23	3241.42	298
9	SEP	1975	24	3178.32	352

1-36 1km (0)
37-72 1.45km (0)
73-108 2.0km (0)
109-144 2.5km (3)
145-180 3.70km (6)
181-216 3.86km (1)
217-252 5.79km (11)
253-288 9.81km (0)
289-324 12km (1)
325-369 16.09km (3)

24-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
3	MAR	1975	24	1467.37	121
13	JAN	1975	24	1152.46	256
21	FEB	1975	24	1130.45	177
3	APR	1975	24	1112.90	121
25	MAR	1975	24	1055.62	226
26	FEB	1975	24	951.38	189
7	AUG	1975	24	930.96	402
19	MAR	1975	24	880.56	257
2	MAR	1975	24	818.09	121
27	FEB	1975	24	790.13	164
6	AUG	1975	24	761.60	257
10	MAY	1975	24	757.16	237
9	NOV	1975	24	745.00	359
24	SEP	1975	24	739.57	237
25	JAN	1975	24	736.91	45
25	FEB	1975	24	721.66	45
11	NOV	1975	24	717.29	177
1	SEP	1975	24	706.72	226
2	FEB	1975	24	706.66	550
13	NOV	1975	24	691.28	120
5	JAN	1975	24	677.75	175
17	DEC	1975	24	663.99	86
16	JAN	1975	24	662.95	121
15	AUG	1975	24	658.09	121
14	NOV	1975	24	656.35	121

1-36 (0)
37-72 (2)
73-108 (1)
109-144 (7)
145-180 (4)
181-216 (2)
217-252 (8)
253-288 (0)
289-324 (0)
325-360 (1)

Table B-6(c). Continued

3-hr/ Selected Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
21	FEB	1975	24	3987.59	213
11	NOV	1975	19	3685.76	213
23	AUG	1975	8	3288.96	238
21	FEB	1975	21	2527.20	213
7	OCT	1975	3	2431.13	238
6	JAN	1975	3	2350.06	213
8	DEC	1975	6	1718.30	238
3	DEC	1975	24	1713.85	213
7	AUG	1975	13	1669.17	238
9	SEP	1975	3	1583.78	238
9	MAY	1975	21	1541.05	238
15	SEP	1975	23	1484.43	213
20	NOV	1975	6	1411.47	213
30	OCT	1975	13	1381.14	238
9	SEP	1975	16	1372.24	238
18	MAR	1975	16	1269.75	213
2	FEB	1975	17	1269.30	238
20	MAY	1975	15	1233.06	38
9	MAY	1975	9	1210.37	238
6	AUG	1975	17	1200.83	238
1	JUL	1975	6	1188.89	238
22	DEC	1975	3	1152.40	238
6	SEP	1975	17	1123.55	238
22	AUG	1975	19	1114.11	238
31	DEC	1975	7	1108.13	238

(238) Dutch Hollow (16)
(165) Petersbung (0)
(213) Wilson Creek (8)
(38) Lawrenceburg (1)
(255) Elizabethtown (0)
(326) Kilby Road (0)

24-hr/ Selected Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
21	FEB	1975	24	955.38	213
2	FEB	1975	24	726.66	238
25	AUG	1975	24	658.09	238
11	NOV	1975	24	597.40	213
9	SEP	1975	24	556.57	238
9	MAY	1975	24	552.32	238
7	AUG	1975	24	501.60	238
24	SEP	1975	24	493.35	238
23	SEP	1975	24	401.20	238
7	OCT	1975	24	334.42	238
18	MAR	1975	24	333.01	213
6	JAN	1975	24	296.70	213
20	NOV	1975	24	295.93	213
30	OCT	1975	24	271.67	238
19	MAY	1975	24	264.19	213
20	MAY	1975	24	262.57	38
26	FEB	1975	24	236.18	255
10	MAY	1975	24	229.04	238
21	OCT	1975	24	228.04	255
10	APR	1975	24	226.75	238
1	JUL	1975	24	223.73	238
4	AUG	1975	24	221.56	238
8	DEC	1975	24	216.65	238
25	APR	1975	24	214.17	238
3	DEC	1975	24	213.86	213

(238) Dutch Hollow (15)
(165) Petersburg (0)
(213) Wilson Creek (7)
(38) Lawrenceburg (1)
(326) Kilby Road (0)

Table B-6(d). CRSTER (Irwin) Calculated Episodes For Tanners Creek 1976

3-hr/ Full Set of Receptors

```
     DATE          HOUR   AVG. CONC.   SITE/RECEPTOR
 5  NOV 1976         6     5705.16         185
23  NOV 1976         7     4586.53         187
30  APR 1976        21     4057.30         359
16  JUL 1976        23     4041.81         196
12  SEP 1976        20     3954.94         177
 8  JAN 1976         8     3745.29         121
 9  JUL 1976        23     3715.36         177
 4  OCT 1976        23     3661.64         177
24  AUG 1976        22     3520.97         244
10  NOV 1976        23     3401.78         187
12  NOV 1976        22     3371.28         121
11  AUG 1976         8     3264.38         177
14  NOV 1976        20     3165.08         121
29  JUL 1976        18     3153.58          45
20  NOV 1976        18     3080.88         116
18  JUN 1976         3     3074.67         212
31  JUL 1976        22     3027.76         196
28  MAY 1976         2     3015.10         245
14  JUL 1976         6     3005.57         297
30  JUL 1976        23     2986.66         121
29  JAN 1976        20     2921.79         165
16  MAR 1976        17     2862.82         120
 7  NOV 1976         8     2724.72         155
24  AUG 1976         6     2685.90         238
26  APR 1976        18     2523.60          94
```

1-36 1km (0)
37-72 1.45km (2)
73-108 2km (0)
109-144 2.5km (5)
145-180 3.70km (8)
171-216 3.86km (5)
217-252 5.79km (3)
253-288 9.81km (0)
289-324 12km (1)
325-360 16.09km (1)

24-hr Full Set of Receptors

```
     DATE          HOUR   AVG. CONC.   SITE/RECEPTOR
 8  NOV 1976        24     1233.32         185
16  MAR 1976        24      845.23         
13  NOV 1976        24      708.62         187
30  APR 1976        24      709.51         359
 4  OCT 1976        24      724.73         177
12  SEP 1976        24      649.00         177
21  DEC 1976        24      624.28          84
16  JUL 1976        24      619.70         196
 3  MAY 1976        24      617.06         120
 8  JAN 1976        24      616.83         121
29  JAN 1976        24      612.64         155
30  JUL 1976        24      602.33         121
 7  NOV 1976        24      594.30         151
10  NOV 1976        24      593.86         126
30  JUN 1976        24      575.79         152
17  MAR 1976        24      563.69         120
16  MAR 1976        24      558.91         238
19  SEP 1976        24      546.34         121
23  JUN 1976        24      546.03         106
 2  AUG 1976        24      542.87         237
24  AUG 1976        24      534.58         238
17  AUG 1976        24      533.25         238
22  NOV 1976        24      523.65         189
13  JUN 1976        24      522.72          38
 9  JUL 1976        24      515.04         177
```

1-36 (0)
37-72 (1)
73-108 (7)
145-180 (6)
181-216 (3)
217-252 (5)
253-288 (0)
289-324 (0)
325-360 (1)

Table B-6(d) continued

3-hr Selected Set of Receptors

```
   DATE              HOUR  AVG. CONC.  SITE/RECEPTOR
 4 OCT 1976           23    2813.65        213
24 AUG 1976            6    2685.90        238
12 SEP 1976           23    2653.58        213
 9 JUL 1976           23    2411.04        213
28 JUL 1976           15    2239.07         38
 5 OCT 1976            1    2129.09        213
11 AUG 1976            7    1974.04        213
27 OCT 1976            4    1826.77        238
12 JAN 1976           21    1823.25        213
 3 AUG 1976            3    1779.87        238
19 OCT 1976            7    1763.30        213
13 JUN 1976           14    1709.67         38
29 JUN 1976           13    1615.66         38
 6 JAN 1976            1    1592.77        213
17 AUG 1976           20    1573.30        238
30 OCT 1976            3    1567.46        213
18 OCT 1976            2    1564.07        238
15 MAR 1976           11    1532.06        238
16 JUN 1976            5    1496.90        213
 2 JUN 1976           11    1475.26        238
22 MAY 1976           16    1443.38        238
13 JUN 1976           18    1335.20         38
26 JUL 1976           21    1325.66        238
15 NOV 1976            3    1313.75        238
18 AUG 1976            9    1313.44        238
```

(238) Dutch Hollow (11)
(165) Petersburg (0)
(213) Wilson Creek (10)
(38) Lawrenceburg (4)
(255) Elizabethtown (0)
(326) Kilby Road (0)

24-hr/ Selected Set of Receptors

```
   DATE              HOUR  AVG. CONC.  SITE/RECEPTOR
 4 OCT 1976           24     585.14        213
15 MAR 1976           24     550.91        238
24 AUG 1976           24     532.54        238
17 AUG 1976           24     525.35        238
13 JUN 1976           24     522.11         38
15 SEP 1976           24     472.15        213
 3 JUN 1976           24     458.42        238
16 AUG 1976           24     408.85        238
27 OCT 1976           24     375.51        238
28 JUL 1976           24     348.81         38
 9 JUL 1976           24     348.30        213
30 OCT 1976           24     347.20        213
21 AUG 1976           24     336.35        238
16 AUG 1976           24     333.86        238
24 MAY 1976           24     333.60        238
29 JUN 1976           24     329.28         38
 3 AUG 1976           24     322.45        238
 2 AUG 1976           24     292.98        165
 8 OCT 1976           24     283.37        238
 5 JUN 1976           24     280.19        238
22 MAY 1976           24     270.44        238
21 AUG 1976           24     246.79        213
16 JAN 1976           24     242.18        213
18 MAR 1976           24     237.47         38
24 APR 1976           24     235.73         38
```

(238) Dutch Hollow (13)
(165) Petersburg (1)
(213) Wilson Creek (6)
(38) Lawrenceburg (5)
(255) Elizabethtown (0)
(326) Kilby Road (0)

Table B-7(a). MPTER (Turner) Calculated Episodes for Muskingum 1975

3-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
31 JUL 1975	12	1055.28	2
20 MAY 1975	14	710.78	6
19 NOV 1975	15	551.68	10
31 JUL 1975	16	542.70	6
3 SEP 1975	14	535.21	7
21 MAY 1975	16	529.85	8
30 SEP 1975	14	518.84	6
14 OCT 1975	14	491.50	6
2 JUL 1975	11	495.05	7
13 OCT 1975	13	483.93	5
16 JUN 1975	14	482.34	6
5 MAR 1975	14	480.06	6
24 JAN 1975	15	463.38	6
25 JUN 1975	15	459.95	5
19 JUL 1975	11	451.15	6
23 AUG 1975	10	437.81	6
20 MAY 1975	11	393.71	8
28 MAY 1975	15	389.74	7
1 APR 1975	11	385.70	6
27 JUL 1975	12	384.19	5
21 MAY 1975	19	378.65	6
21 OCT 1975	13	378.33	6
28 MAY 1975	13	374.98	2
9 JAN 1975	14	374.58	8
14 OCT 1975	11	374.34	6

1 1km (0)[a]
2 1.5km (2)
3 2km (0)
4 2.5km (0)
5 3km (3)
6 4.34km (13)
7 5.31km (3)
8 8.05km (3)
9 12km (0)
10 19.79km (1)

24-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
31 JUL 1975	24	150.32	2
20 MAY 1975	24	142.98	6
14 OCT 1975	24	110.72	6
21 MAY 1975	24	108.40	8
19 JUL 1975	24	102.65	8
2 JUL 1975	24	86.90	7
30 SEP 1975	24	84.55	6
29 JAN 1975	24	77.48	10
25 JUN 1975	24	75.04	6
13 OCT 1975	24	74.00	6
19 MAY 1975	24	73.47	8
5 JAN 1975	24	70.57	9
9 JUL 1975	24	69.56	8
19 NOV 1975	24	68.98	10
21 OCT 1975	24	67.41	10
3 SEP 1975	24	66.96	7
5 MAR 1975	24	64.72	6
23 JUN 1975	24	62.23	6
4 JUN 1975	24	61.89	8
14 JUN 1975	24	61.06	6
24 JUL 1975	24	60.98	10
21 APR 1975	24	58.23	7
24 JAN 1975	24	57.92	6
23 AUG 1975	24	57.58	6
5 MAY 1975	24	54.87	7

1 (0)
2 (1)
3 (0)
4 (0)
5 (0)
6 (10)
7 (4)
8 (5)
9 (1)
10 (4)

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[a] Number of Cases

Table B-7(a). Continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1978	14	711.78	6
19 NOV 1978	15	661.68	10
31 JUL 1976	16	642.70	6
3 SEP 1976	14	636.21	7
21 MAY 1978	16	629.85	8
30 SEP 1975	19	618.84	6
16 OCT 1976	14	491.50	6
2 JUL 1978	11	485.05	7
14 JUN 1977	14	482.34	6
5 MAR 1978	14	480.06	6
31 JUL 1976	12	478.92	6
24 JAN 1977	16	463.38	6
19 JUL 1977	11	451.16	6
23 AUG 1975	10	437.81	6
20 MAY 1977	11	393.71	6
28 MAY 1976	15	389.74	8
13 OCT 1976	13	388.94	7
1 APR 1975	11	385.70	6
21 MAY 1978	19	378.68	8
21 OCT 1975	13	378.33	6
2 JAN 1976	14	374.56	6
14 OCT 1978	11	374.34	6
25 JUN 1978	15	371.01	6
19 JUL 1977	16	356.77	8
23 JUL 1977	14	352.40	7

(6) Hackney 16
(7) Beverly 4
(8) Rich Valley 4
(10) Caldwell 1

24-hr Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1976	24	142.95	6
31 JUL 1978	24	127.71	6
16 OCT 1976	24	110.72	8
21 MAY 1978	24	108.40	8
19 JUL 1978	24	102.65	6
2 JUL 1978	24	88.90	7
30 SEP 1975	24	84.05	8
29 JAN 1978	24	77.48	10
25 JUN 1978	24	75.04	6
13 OCT 1976	24	74.00	6
19 MAY 1978	24	73.47	8
9 JUL 1977	24	69.06	8
18 NOV 1975	24	68.96	10
21 OCT 1978	24	67.41	10
7 SEP 1976	24	66.98	7
2 MAR 1978	24	64.72	6
23 JUN 1978	24	62.23	8
6 JUN 1977	24	61.89	6
14 JUN 1978	24	61.06	6
24 JUL 1978	24	60.96	10
21 APR 1975	24	58.23	7
24 JAN 1975	24	57.92	6
23 AUG 1975	24	57.58	6
2 JAN 1976	24	56.85	8
5 MAY 1978	24	54.97	7

(6) Hackney 11
(7) Beverly 4
(8) Rich Valley 6
(10) Caldwell 4

Table B-7(b). MPTER (Turner) Calculated Episodes for Muskingum 1976

3-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
9	JUL	1976	15	1247.54	2
28	JUN	1976	14	1201.87	2
12	JUN	1976	13	1186.88	1
10	MAY	1976	13	914.08	2
22	MAY	1976	15	845.06	2
21	JUL	1976	12	810.04	6
16	APR	1976	11	693.06	5
11	AUG	1976	10	662.74	5
13	SEP	1976	14	655.90	6
18	JUL	1976	13	643.48	1
28	JUN	1976	10	620.12	7
9	JUN	1976	12	614.15	3
10	AUG	1976	16	600.68	7
22	AUG	1976	15	587.72	7
13	APR	1976	14	562.24	6
6	MAY	1976	13	533.46	3
5	APR	1976	12	515.50	6
12	JUN	1976	10	512.57	6
13	AUG	1976	13	509.51	5
12	AUG	1976	18	477.48	6
15	JUL	1976	15	467.73	5
28	JUL	1976	17	446.53	5
13	MAY	1976	14	435.13	5
30	APR	1976	14	433.24	5
2	MAR	1976	13	425.46	10

1 1km (2)[a]
2 1.5km (4)
3 2km (2)
4 2.5km (0)
5 3km (7)
6 4.34km (6)
7 5.31km (3)
8 8.05km (0)
9 12km (0)
10 19.79km (1)

24-hr/ Full Set of Receptors

DATE			HOUR	AVG. CONC.	SITE/RECEPTOR
9	JUL	1976	24	157.19	2
12	JUN	1976	24	150.87	1
20	JUN	1976	24	150.29	2
10	AUG	1976	24	120.73	7
10	MAY	1976	24	114.29	2
22	MAY	1976	24	108.13	2
21	JUL	1976	24	102.90	6
12	AUG	1976	24	101.86	8
16	APR	1976	24	89.68	5
22	AUG	1976	24	86.55	7
11	AUG	1976	24	82.84	5
13	SEP	1976	24	82.00	6
28	JUN	1976	24	81.76	8
6	MAY	1976	24	80.73	8
18	JUL	1976	24	80.50	1
15	FEB	1976	24	79.47	10
28	JUL	1976	24	77.94	6
9	JUN	1976	24	76.95	3
9	MAY	1976	24	73.08	3
14	JUL	1976	24	71.12	6
2	MAR	1976	24	70.43	10
13	APR	1976	24	70.30	6
19	MAY	1976	24	70.18	7
5	APR	1976	24	64.79	6
13	AUG	1976	24	64.00	5

1 (2)
2 (4)
3 (2)
4 (0)
5 (3)
6 (6)
7 (3)
8 (3)
9 (0)
10 (2)

Table B-7(b) continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 JUL 1976	12	810.04	6
12 JUN 1976	11	667.55	6
13 SEP 1976	14	655.90	6
16 APR 1976	11	646.50	6
28 JUN 1976	10	620.12	7
10 AUG 1976	16	600.68	7
22 AUG 1976	15	587.72	7
11 AUG 1976	11	568.09	6
13 APR 1976	14	562.24	6
9 JUL 1976	15	548.62	6
10 MAY 1976	13	523.54	6
5 APR 1976	12	515.50	6
18 JUL 1976	13	478.32	6
12 AUG 1976	16	477.48	6
9 JUN 1976	11	474.43	6
26 JUN 1976	14	454.98	6
13 AUG 1976	13	442.21	6
2 MAR 1976	13	425.46	10
30 JUN 1976	14	412.25	6
23 APR 1976	11	410.81	7
19 MAY 1976	12	409.27	7
28 JUL 1976	16	406.07	6
27 AUG 1976	16	397.24	8
22 MAY 1976	14	395.12	6
25 AUG 1976	15	384.05	8

(6) Hackney 17
(7) Beverly 5
(8) Rich Valley 2
(10) Caldwell 1

24-hr Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
10 AUG 1976	24	120.73	7
12 JUN 1976	24	105.13	6
21 JUL 1976	24	102.90	6
12 AUG 1976	24	101.66	8
22 AUG 1976	24	86.50	7
16 APR 1976	24	84.27	6
13 SEP 1976	24	82.00	6
28 JUN 1976	24	81.76	8
6 MAY 1976	24	80.73	8
15 FEB 1976	24	79.47	10
28 JUL 1976	24	77.94	6
18 JUL 1976	24	74.49	6
14 JUL 1976	24	71.12	6
11 AUG 1976	24	71.11	6
2 MAR 1976	24	70.43	10
13 APR 1976	24	70.30	6
19 MAY 1976	24	70.18	7
10 MAY 1976	24	69.23	6
9 JUL 1976	24	68.60	6
5 APR 1976	24	66.79	6
22 MAY 1976	24	66.10	7
3 MAR 1976	24	62.92	10
23 APR 1976	24	62.73	7
13 JUL 1976	24	61.39	7
25 FEB 1976	24	60.24	6

(6) Hackney 13
(7) Beverly 6
(8) Rich Valley 3
(10) Caldwell 3

[a] Number of Cases

Table B-7(c). Irwin (MULTP) Calculated Episodes for Muskingum 1975

3-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1975	14	837.35	5
21 MAY 1975	18	791.26	5
25 JUN 1975	15	775.99	1
17 JUL 1975	13	727.21	3
14 JUN 1975	14	674.92	3
31 JUL 1975	16	669.35	3
19 MAY 1975	16	668.16	1
30 SEP 1975	14	640.88	5
21 OCT 1975	13	632.71	5
14 OCT 1975	14	605.90	5
3 JUN 1975	17	602.79	5
5 MAR 1975	14	571.65	5
2 AUG 1975	12	528.96	1
20 MAY 1975	18	492.60	3
19 JUL 1975	10	490.03	6
31 MAY 1975	12	481.63	1
5 JAN 1975	16	475.29	6
24 JAN 1975	15	454.32	6
30 MAY 1975	14	446.99	3
26 MAY 1975	13	410.94	1
10 MAY 1975	18	410.21	7
31 MAR 1975	16	404.41	1
1 APR 1975	11	402.90	6
2 APR 1975	15	400.39	5
7 SEP 1975	17	392.46	3

1 1km (6)[a]
2 1.5km (0)
3 2km (6)
4 2.5km (0)
5 3km (8)
6 4.34km (4)
7 5.31km (1)
8 8.05km (0)
9 12km (0)
10 19.79km (0)

24-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
10 JUL 1975	24	183.01	3
20 MAY 1975	24	181.06	6
21 MAY 1975	24	129.70	8
19 MAY 1975	24	118.71	2
31 JUL 1975	24	116.37	3
31 MAY 1975	24	111.08	3
20 JUN 1975	24	103.04	1
21 OCT 1975	24	96.66	8
5 MAR 1975	24	89.39	5
14 OCT 1975	24	89.32	5
30 SEP 1975	24	87.37	3
14 JUN 1975	24	86.64	3
2 JUL 1975	24	86.30	7
20 JAN 1975	24	80.82	8
3 JUN 1975	24	80.46	5
7 SEP 1975	24	79.30	3
4 JUN 1975	24	70.42	5
9 JUL 1975	24	69.93	5
5 JAN 1975	24	68.61	6
5 MAY 1975	24	68.23	7
2 AUG 1975	24	66.14	1
21 APR 1975	24	65.40	7
30 AUG 1975	24	61.56	5
27 JUL 1975	24	60.10	3
25 FEB 1975	24	58.94	9

1 (2)
2 (1)
3 (7)
4 (0)
5 (6)
6 (2)
7 (3)
8 (3)
9 (1)
10 (0)

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[a] Number of Cases

Table B-7(c). Continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1975	14	760.91	6
21 MAY 1975	16	742.61	6
21 OCT 1975	13	694.22	6
14 JUN 1975	14	691.71	6
30 SEP 1975	14	678.90	6
19 JUL 1975	11	676.26	6
14 OCT 1975	14	672.24	6
19 JUL 1975	14	645.85	6
5 MAR 1975	14	641.28	6
3 JUN 1975	17	622.80	6
8 JAN 1975	16	476.29	6
31 JUL 1975	15	469.61	6
24 JAN 1975	15	454.32	6
10 MAY 1975	18	410.21	7
1 APR 1975	11	402.90	6
20 MAY 1975	18	381.20	6
3 SEP 1975	14	375.67	7
7 JUL 1975	11	365.94	7
30 MAY 1975	14	362.94	6
25 JUN 1975	15	359.09	6
10 APR 1975	12	358.28	7
25 FEB 1975	12	354.05	8
5 MAY 1975	14	347.35	7
22 JUL 1975	17	345.47	7
2 APR 1975	15	339.63	6

(6) Hackney 18
(7) Beverly 6
(8) Rich Valley 1
(10) Caldwell 0

24-hr Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1975	24	164.46	6
19 JUL 1975	24	160.32	6
21 MAY 1975	24	127.51	6
21 OCT 1975	24	96.66	8
31 JUL 1975	24	90.66	6
14 OCT 1975	24	88.02	6
2 JUL 1975	24	86.30	7
19 MAY 1975	24	85.01	6
5 MAR 1975	24	80.92	6
29 JAN 1975	24	80.82	8
31 MAY 1975	24	77.85	6
30 SEP 1975	24	75.14	6
14 JUN 1975	24	74.24	6
3 JUN 1975	24	72.02	6
9 JUL 1975	24	69.93	8
8 JAN 1975	24	68.81	6
5 MAY 1975	24	68.23	7
4 JUN 1975	24	66.63	6
21 APR 1975	24	65.49	7
25 JUN 1975	24	64.83	6
30 AUG 1975	24	61.54	6
10 MAY 1975	24	57.65	7
24 JAN 1975	24	56.79	6
1 APR 1975	24	54.41	6
22 JUL 1975	24	53.84	7

(6) Hackney 17
(7) Beverly 5
(8) Rich Valley 3
(10) Caldwell 0

Table B-7(d). Irwin (MULTP) Calculated Episodes for Muskingum 1976

3-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 JUL 1976	12	1207.90	3
10 MAY 1976	13	1030.20	1
12 AUG 1976	18	849.60	8
30 APR 1976	14	839.32	1
13 SEP 1976	14	829.39	6
[illegible] MAY 1976	15	793.81	2
10 AUG 1976	17	675.21	7
5 APR 1976	12	650.46	6
13 APR 1976	14	639.70	5
12 JUN 1976	13	624.83	1
30 JUN 1976	14	621.86	6
22 AUG 1976	15	559.89	7
10 MAR 1976	16	550.97	3
23 JUL 1976	13	543.80	1
13 MAY 1976	14	543.14	1
10 AUG 1976	14	540.97	7
22 MAY 1976	18	536.41	7
28 AUG 1976	15	529.09	3
13 AUG 1976	13	528.06	3
22 JUN 1976	14	524.49	[illegible]
18 JUL 1976	13	520.03	3
10 JUN 1976	17	518.12	2
24 APR 1976	15	513.39	3
28 JUN 1976	13	509.81	[illegible]
23 MAR 1976	15	505.98	1

1	1km (6)[a]	6	4.34km (2)
2	1.5km (2)	7	5.31km (4)
3	2km (6)	8	8.05km (0)
4	2.5km (0)	9	12km (0)
5	3km (5)	10	19.79km (0)

24-hr/ Full Set of Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 JUL 1976	24	175.80	5
12 AUG 1976	24	186.96	8
10 AUG 1976	24	152.08	7
10 MAY 1976	24	150.84	1
12 JUN 1976	24	119.76	2
18 FEB 1976	24	108.15	8
[illegible] MAY 1976	24	107.71	2
30 JUN 1976	24	106.08	8
30 APR 1976	24	104.90	1
10 MAR 1976	24	104.09	3
13 SEP 1976	24	103.85	5
22 MAY 1976	24	100.66	7
10 JUN 1976	24	97.94	1
23 MAR 1976	24	90.64	1
25 FEB 1976	24	91.94	5
6 MAY 1976	24	88.52	8
28 JUN 1976	24	88.49	8
22 AUG 1976	24	87.77	7
16 APR 1976	24	87.38	3
14 JUN 1976	24	84.76	5
9 MAY 1976	24	83.57	1
[illegible] APR 1976	24	82.61	6
19 APR 1976	24	82.35	2
13 APR 1976	24	79.96	5
5 MAR 1976	24	75.46	8

1 (5)	6 (1)
2 (3)	7 (3)
3 (3)	8 (5)
4 (0)	9 (0)
5 (5)	10(0)

Table B-7(d) continued

3-hr/ Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 JUL 1976	12	955.70	6
13 SEP 1976	14	757.99	6
12 AUG 1976	18	748.50	6
10 AUG 1976	17	675.21	7
5 APR 1976	12	650.46	6
30 JUN 1976	14	621.86	6
13 APR 1976	14	612.43	6
12 JUN 1976	11	565.84	6
22 AUG 1976	15	559.69	7
10 AUG 1976	14	540.97	7
22 MAY 1976	18	536.41	7
28 JUN 1976	13	488.64	6
16 APR 1976	11	485.43	6
20 DEC 1976	12	477.88	6
8 MAY 1976	15	457.63	6
10 MAY 1976	13	447.13	6
15 JUN 1976	12	442.36	8
13 AUG 1976	13	441.62	6
22 JUN 1976	14	438.22	6
10 MAR 1976	17	437.39	6
18 JUL 1976	13	431.98	6
25 MAR 1976	18	425.85	6
20 MAY 1976	11	417.63	6
17 JUL 1976	18	410.84	7
25 AUG 1976	15	400.24	8

(6)	Hackney	18
(7)	Beverly	5
(8)	Rich Valley	2
(10)	Caldwell	0

24-hr Selected Receptors

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
10 AUG 1976	24	152.08	7
12 AUG 1976	24	139.06	6
21 JUL 1976	24	132.13	6
15 FEB 1976	24	108.15	8
30 JUN 1976	24	106.08	8
22 MAY 1976	24	100.66	7
12 JUN 1976	24	95.04	6
13 SEP 1976	24	94.86	6
8 MAY 1976	24	88.52	8
28 JUN 1976	24	88.49	8
22 AUG 1976	24	87.77	7
10 MAR 1976	24	85.18	6
5 APR 1976	24	82.61	6
25 FEB 1976	24	80.96	6
13 APR 1976	24	76.55	6
5 MAR 1976	24	75.46	8
10 MAY 1976	24	74.95	6
14 JUN 1976	24	74.78	6
16 APR 1976	24	74.28	6
14 JUL 1976	24	73.92	6
18 JUL 1976	24	73.35	6
29 APR 1976	24	70.37	7
5 MAY 1976	24	69.70	6
8 FEB 1976	24	67.36	8
3 MAR 1976	24	65.36	6

(6)	Hackney	15
(7)	Beverly	4
(8)	Rich Valley	6
(10)	Caldwell	0

[a] Number of Cases

Table B-8(a). MPTER (Turner) Calculated Episodes for Gavin-Kyger-Sporn 1975

3hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
19 NOV 1975	15	1155.20	3
20 MAY 1975	13	632.71	3
1 NOV 1975	23	544.03	4
2 JUN 1975	6	533.50	4
28 JUN 1975	14	517.60	1
10 NOV 1975	9	516.82	4
28 JUN 1975	10	515.40	1
4 JUN 1975	12	504.95	3
16 OCT 1975	3	501.30	7
23 JUN 1975	9	498.66	4
6 JUN 1975	9	487.42	3
21 MAY 1975	16	471.49	3
28 AUG 1975	10	445.65	1
21 AUG 1975	13	442.58	3
20 MAY 1975	16	434.42	3
22 NOV 1975	3	431.67	6
21 OCT 1975	6	429.52	4
15 OCT 1975	7	424.99	4
23 JUN 1975	14	422.62	6
26 AUG 1975	9	420.27	4
14 NOV 1975	22	413.05	11
6 DEC 1975	2	411.87	4
4 DEC 1975	17	410.25	11
1 APR 1975	14	407.37	4
21 OCT 1975	13	405.83	5

1 Kerr 3
2 Henderson 0
3 Lakin 7
4 Wolfpen 9
5 Mason 1
6 New Haven 2
7 Mount Alto 1
8 Five Points 0
9 Dorcas 0
10 Coolville 0
11 Neptune 2

24hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
20 MAY 1975	24	158.05	3
4 APR 1975	24	156.58	7
19 NOV 1975	24	144.41	3
28 JUN 1975	24	138.80	1
10 SEP 1975	24	137.12	1
1 NOV 1975	24	134.64	4
21 OCT 1975	24	127.73	4
4 JUN 1975	24	119.93	3
21 MAY 1975	24	109.48	3
11 SEP 1975	24	108.80	4
28 AUG 1975	24	100.48	1
2 JUN 1975	24	100.16	4
28 FEB 1975	24	91.14	8
19 JUL 1975	24	88.90	3
15 JUN 1975	24	88.20	4
22 JUN 1975	24	87.49	4
15 NOV 1975	24	86.27	4
[illegible] SEP 1975	24	83.78	4
19 MAY 1975	24	83.40	3
26 AUG 1975	24	82.73	4
1 APR 1975	24	82.43	11
14 DEC 1975	24	79.26	4
13 FEB 1975	24	79.21	7
23 JUN 1975	24	78.96	4
9 OCT 1975	24	78.21	4

1 Kerr 3
2 Henderson 0
3 Lakin 6
4 Wolfpen 12
5 Mason 0
6 New Haven 0
7 Mount Alto 2
8 Five Points 1
9 Dorcas 0
10 Coolville 0
11 Neptune 1

Table B-8(b). MPTER (Turner) Calculated Episodes for Gavin-Kyger-Sporn 1976

3hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
[illegible]	[illegible]	[illegible]	[illegible]

1 Kerr 2
2 Henderson 1
3 Lakin 2
4 Wolfpen 16
5 Mason 0
6 New Haven 2
7 Mount Alto 2
8 Five Points 0
9 Dorcas 0
10 Coolville 0
11 Neptune 0

24hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
[illegible]	[illegible]	[illegible]	[illegible]

1 Kerr 3
2 Henderson 0
3 Lakin 1
4 Wolfpen 16
5 Mason 0
6 New Haven 2
7 Mount Alto 1
8 Five Points 0
9 Dorcas 0
10 Coolville 0
11 Neptune 2

Table B-8(c). Irwin (MULTP) Calculated Episodes for Gavin-Kyger-Sporn 1975

3hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 OCT 1975	6	806.10	4
19 DEC 1975	8	786.15	6
6 DEC 1975	2	764.43	4
20 MAY 1975	13	723.44	3
1 NOV 1975	23	683.42	4
15 OCT 1975	7	658.60	4
1 NOV 1975	20	586.13	4
11 JAN 1975	24	529.17	6
28 JUN 1975	10	525.05	1
4 JUN 1975	12	523.22	3
26 AUG 1975	3	496.26	4
23 AUG 1975	6	495.21	4
3 OCT 1975	16	474.74	4
10 NOV 1975	9	460.84	4
20 MAY 1975	16	457.66	3
7 NOV 1975	22	442.76	4
23 JUN 1975	8	441.56	4
28 JUN 1975	14	441.28	1
21 MAY 1975	16	438.67	3
9 JUN 1975	18	434.82	1
22 NOV 1975	3	434.66	6
16 OCT 1975	2	431.26	7
22 JUN 1975	23	425.26	4
16 JAN 1975	23	406.95	6
9 NOV 1975	12	402.91	4

1	Kerr	3
2	Henderson	0
3	Lakin	4
4	Wolfpen	13
5	Mason	0
6	New Haven	4
7	Mount Alto	1
8	Five Points	0
9	Dorcas	0
10	Coolville	0
11	Neptune	0

24hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
21 OCT 1975	24	203.47	4
15 NOV 1975	24	169.87	4
1 NOV 1975	24	164.70	4
20 MAY 1975	24	156.63	3
4 APR 1975	24	150.24	7
28 JUN 1975	24	131.47	1
22 JUN 1975	24	123.41	4
8 FEB 1975	24	117.53	4
4 JUN 1975	24	113.86	3
10 SEP 1975	24	109.91	1
23 AUG 1975	24	105.07	4
7 NOV 1975	24	103.67	4
20 JAN 1975	24	101.61	3
15 JUN 1975	24	101.58	4
11 SEP 1975	24	100.93	4
14 DEC 1975	24	98.73	4
28 AUG 1975	24	97.94	1
19 MAY 1975	24	97.53	3
5 DEC 1975	24	92.50	4
11 JAN 1975	24	90.61	6
6 DEC 1975	24	90.20	4
19 JUL 1975	24	87.03	3
2 MAR 1975	24	83.41	7
15 OCT 1975	24	82.35	4
21 MAY 1975	24	81.27	3

1	Kerr	3
2	Henderson	0
3	Lakin	6
4	Wolfpen	13
5	Mason	0
6	New Haven	1
7	Mount Alto	2
8	Five Points	0
9	Dorcas	0
10	Coolville	0
11	Neptune	0

Table B-8(d). Irwin (MULTP) Calculated Episodes for Gavin-Kyger-Sporn 1976

3hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
25 FEB 1976	8	959.70	4
10 JUL 1976	24	734.11	4
23 FEB 1976	21	701.83	4
3 JUL 1976	1	698.19	4
20 MAR 1976	2	674.41	4
11 MAY 1976	1	669.83	4
14 JUL 1976	23	660.41	4
4 JUN 1976	12	660.29	1
5 MAR 1976	23	605.07	7
2 MAR 1976	7	587.72	4
9 OCT 1976	24	584.25	6
15 DEC 1976	19	583.50	4
20 FEB 1976	8	577.93	4
28 JUN 1976	22	568.14	4
13 DEC 1976	16	530.41	2
22 AUG 1976	21	501.66	4
17 MAY 1976	2	499.95	4
26 FEB 1976	1	498.43	4
17 DEC 1976	18	493.39	7
1 DEC 1976	19	490.05	4
12 OCT 1976	23	487.80	4
24 FEB 1976	4	485.09	4
25 FEB 1976	3	471.19	4
19 AUG 1976	17	469.46	3
29 APR 1976	24	464.43	6

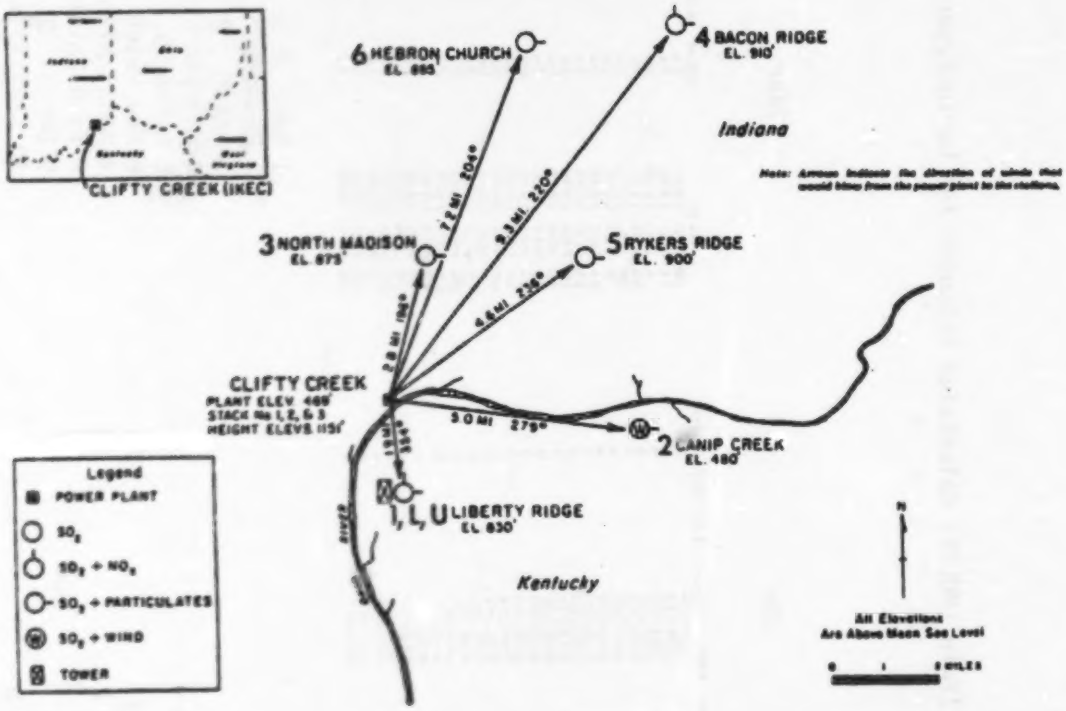
1 Kerr 1
2 Henderson 1
3 Lakin 1
4 Wolfpen 18
5 Mason 0
6 New Haven 2
7 Mount Alto 2
8 Five Points 0
9 Dorcas 0
10 Coolville 0
11 Neptune 0

24hr

DATE	HOUR	AVG. CONC.	SITE/RECEPTOR
25 FEB 1976	24	261.43	4
14 JUL 1976	24	189.21	4
4 JUN 1976	24	179.85	1
20 MAR 1976	24	160.70	4
10 JUL 1976	24	159.76	4
2 MAR 1976	24	159.12	4
22 DEC 1976	24	155.89	4
15 JUN 1976	24	154.92	4
15 FEB 1976	24	137.74	3
10 NOV 1976	24	132.05	6
27 MAY 1976	24	129.06	1
14 MAR 1976	24	123.15	4
10 FEB 1976	24	123.10	4
28 AUG 1976	24	122.94	4
7 JUL 1976	24	121.60	4
19 MAR 1976	24	120.29	4
24 FEB 1976	24	116.29	4
15 DEC 1976	24	113.87	4
23 FEB 1976	24	113.60	4
12 AUG 1976	24	113.44	3
29 JUN 1976	24	110.90	4
25 APR 1976	24	109.33	6
1 DEC 1976	24	107.70	4
22 FEB 1976	24	106.88	7
10 MAY 1976	24	105.88	4

1 Kerr 2
2 Henderson 0
3 Lakin 2
4 Wolfpen 18
5 Mason 0
6 New Haven 2
7 Mount Alto 1
8 Five Points 0
9 Dorcas 0
10 Coolville 0
11 Neptune 0

Figure B-1 Field Monitoring Network in the Vicinity of the Clifty Creek Power Plant


Indiana
Ohio
Kentucky
West Virginia
CLIFTY CREEK (IKEC)
6 HEBRON CHURCH
EL. 885'
4 BACON RIDGE
EL. 910'
3 NORTH MADISON
EL. 875'
5 RYKERS RIDGE
EL. 900'
7.2 MI 204°
9.3 MI 220°
4.6 MI 236°
2.8 MI 196°
CLIFTY CREEK
PLANT ELEV. 469'
STACK No 1, 2, & 3
HEIGHT ELEVS 1151'
5.0 MI 279°
2 CANIP CREEK
EL. 480'
1.9 MI 355°
1, L, U LIBERTY RIDGE
EL. 830'
OHIO RIVER
Indiana
Kentucky
Legend
■ POWER PLANT
○ SO_2
$SO_2 + NO_x$
SO_2 + PARTICULATES
Ⓦ SO_2 + WIND
TOWER
N
All Elevations Are Above Mean Sea Level
0 1 2 MILES

Note: Arrows indicate the direction of winds that would blow from the power plant to the stations.

Figure B-2. Field Monitoring Network in the Vicinity of the Tanners Creek Power Plant

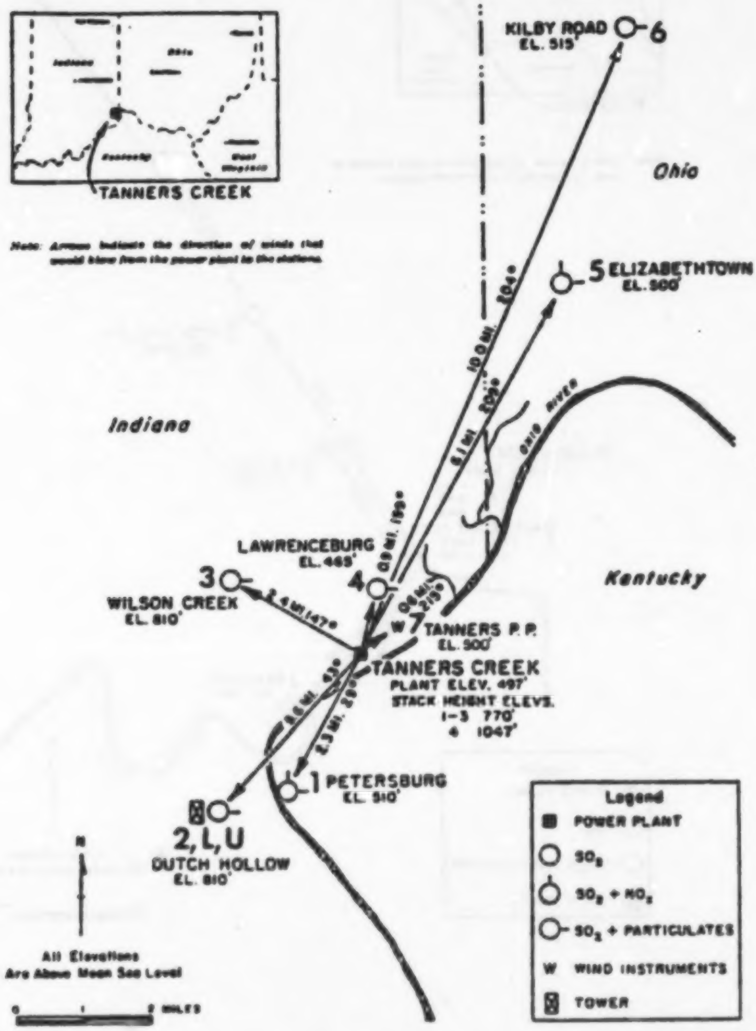

TANNERS CREEK
Note: Arrows indicate the direction of winds that would blow from the power plant to the stations.
KILBY ROAD
EL. 515'
6
Ohio
5 ELIZABETHTOWN
EL. 500'
10.0 MI. 204°
8.1 MI. 209°
Indiana
OHIO RIVER
LAWRENCEBURG
EL. 465'
0.9 MI. 199°
3
4
Kentucky
WILSON CREEK
EL. 810'
2.4 MI. 147°
0.6 MI. 215°
W 7 TANNERS P.P.
EL. 500'
TANNERS CREEK
PLANT ELEV. 497'
STACK HEIGHT ELEVS.
1-3 770'
4 1047'
3.6 MI. 43°
2.3 MI. 20°
1 PETERSBURG
EL. 510'
2, L, U
DUTCH HOLLOW
EL. 810'
N
All Elevations Are Above Mean Sea Level
0
1
2 MILES
Legend
POWER PLANT
SO_2
$SO_2 + NO_2$
SO_2 + PARTICULATES
W WIND INSTRUMENTS
TOWER

Figure B-3 Field Monitoring Network for the Muskingum Plant

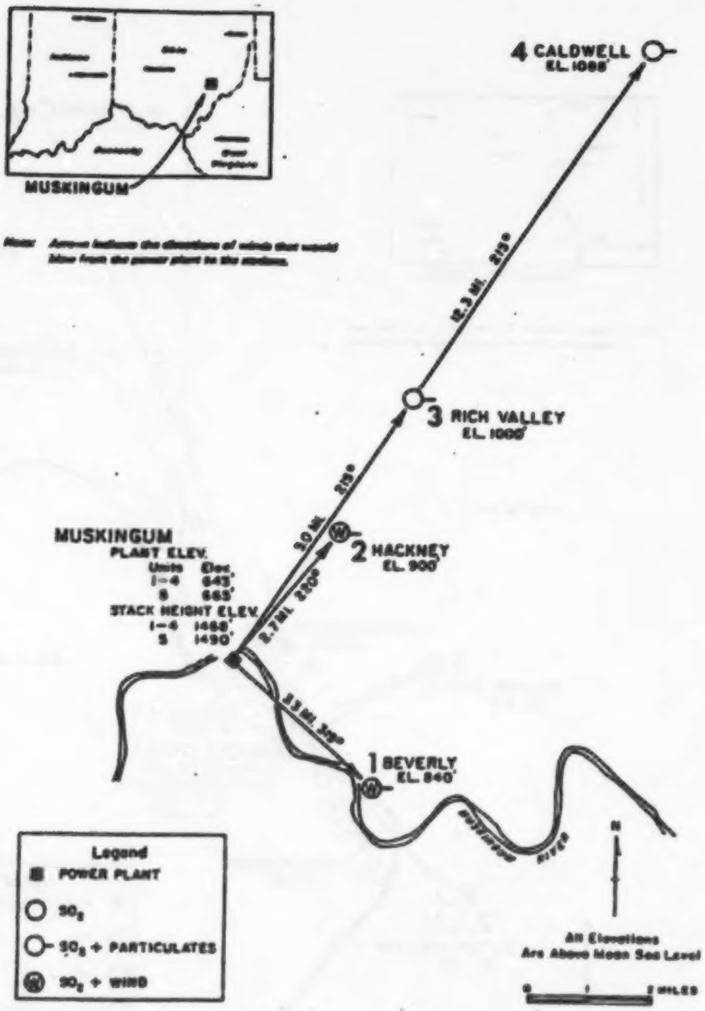
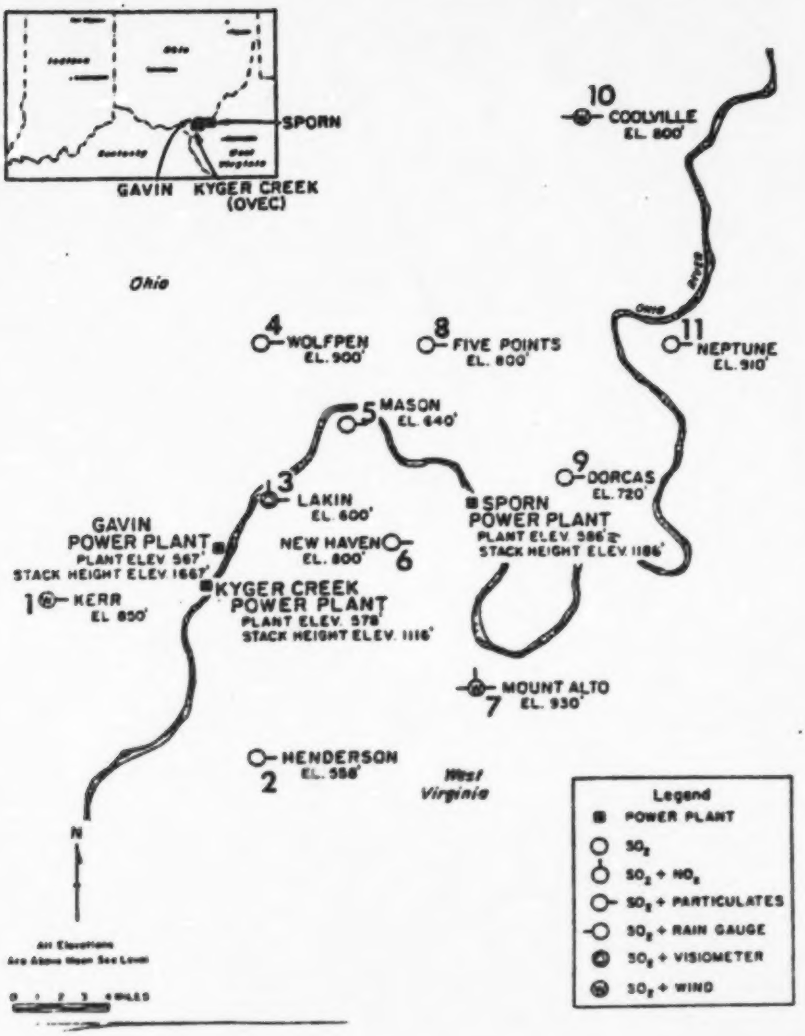

MUSKINGUM
4 CALDWELL
EL. 1088'
12.3 MI. 215°
3 RICH VALLEY
EL. 1000'
5.0 MI. 215°
2 HACKNEY
EL. 900'
2.7 MI. 220°
MUSKINGUM
PLANT ELEV.
Units Elec.
1-4 643'
5 663'
STACK HEIGHT ELEV.
1-4 1468'
5 1490'
3.3 MI. 339°
1 BEVERLY
EL. 840'
RIVER
N
All Elevations
Are Above Mean Sea Level
0 1 2 MILES
Legend
■ POWER PLANT
○ SO_2
○- SO_2 + PARTICULATES
Ⓦ SO_2 + WIND

Figure B-4. Field Monitoring Network in the Vicinity of the Gavin-Kyger-Sporn Power Plant


SPORN
GAVIN
KYGER CREEK (OVEC)
Ohio
10 COOLVILLE EL. 800'
4 WOLFPEN EL. 900'
8 FIVE POINTS EL. 800'
11 NEPTUNE EL. 910'
Ohio River
5 MASON EL. 640'
9 DORCAS EL. 720'
3 LAKIN EL. 600'
SPORN POWER PLANT PLANT ELEV. 586'2" STACK HEIGHT ELEV. 1186'
GAVIN POWER PLANT PLANT ELEV. 567' STACK HEIGHT ELEV. 1667'
NEW HAVEN 6 EL. 800'
1 KERR EL. 850'
KYGER CREEK POWER PLANT PLANT ELEV. 578' STACK HEIGHT ELEV. 1116'
MOUNT ALTO 7 EL. 930'
HENDERSON 2 EL. 558'
West Virginia
N
All Elevations Are Above Mean Sea Level
0 1 2 3 4 MILES
Legend
POWER PLANT
SO2
SO2 + NO2
SO2 + PARTICULATES
SO2 + RAIN GAUGE
SO2 + VISIOMETER
SO2 + WIND

Appendix C

Background Concentration Calculation

APPENDIX C

Background Concentration Calculation at Clifty Creek

Background concentrations must be considered in the comparison of measured and predicted concentration estimates. The problem is more acute for longer averaging times such as 24-hours. In this study three different approaches were used to assess background air quality. Background air quality relevant to the Clifty Creek station includes pollutant concentrations due to natural sources and distant, unidentified man-made sources[27].

The three approaches were tried in order to assess the relative differences in their accuracy and the effects of each on the model evaluation. In order of increasing complexity, the three background calculation methods are: finding the minimum concentration in the station network, calculating the average of all concentrations in the station network and using the EPA Guideline method. The guideline method determines the average of the concentrations at monitors which are not being directly affected (impacted) by the source. For this analysis, impaction was assumed to occur when the wind direction was within 30° of the source-monitor centerline. The Guideline method was used for all analyses for the Clifty Creek plant.

Background concentrations were calculated for 1 hr, 3 hr, and 24 hr periods. The minimum values of the 1 hr, 3 hr, and 24 hr measured concentrations were used for the first method. Similarly, the 1 hr, 3 hr, and 24 hr measured concentrations were averaged for the mean background method. The 3 hr and 24 hr background concentrations calculated using the Guideline method were averages of the hourly background estimates described above.

Table C-1 summarizes background air quality statistics for the three methods described above. Obviously, the average of all observed stations will include the effects of the plume and this fact is reflected in the larger numbers for the mean, standard deviation, and observed maximum. The average concentrations by the minimum method are much lower than for the guideline method, but the 24 hr maximum by the first method exceeds the guideline method. This probably occurs because the 24 hr minimum was used rather than the average of the hourly minimum values.

Although the average method can be rejected, there is not as clear cut a choice between the other two methods. One of the difficulties with the guideline method is its inability to eliminate all effects of the source. The residuals analysis provides some useful information about this problem. The predicted concentrations are essentially zero when the wind direction is outside of a 60° sector centered around the source-receptor centerline. For example, the maximum CRSTER (Irwin) predicted concentration at 15 km from the station outside of the 60° sector was 0.002μg/m^3. Therefore, when the residuals are considered only for the times when the wind direction is outside of the 60° sector, the residuals become the difference between background and observed only.

Table C-2 summarizes the residual results. The T-statistic was used to determine if there was a significant difference between the average residual and the expected mean. In this case, we expect the residuals to be zero because we hypothesize that the difference

Table C-1

Background Concentration Summary

Statistic	Averaging Time	Minimum	Background Average	Background Guideline
Number of Observations	1	8329	8329	8285
	3	8317	8317	8250
	24	343	343	343
Average Concentrations	1	13.4	36.2	28.5
	3	14.5	36.2	28.4
	24	18.9	36.0	28.5
Standard Deviations	1	17.4	37.1	30.0
	3	17.7	34.2	27.6
	24	16.2	22.6	18.4
Maximum Observed	1	191	421	308
	3	170	330	254
	24	113	159	108

Table C-2

Clifty Creek Residuals for Background Cases

(Residual = Background - Observed)

Statistic	Wind Direction	1 Bacon Ridge	2 Rykers Ridge	3 North Madison	4 Hebron Church	5 Liberty Ridge	6 Canip Creek	All Sites
$\bar{x}$	-180° to -60°	-1.47	0.797	-5.11	3.63	-3.94	6.50	0.106
n		2161	2286	2117	2266	4416	3317	17585
s		35.1	18.9	31.2	22.6	14.6	18.6	23.6
t		-1.95	2.02	-7.53	7.64	-17.9	20.1	0.596
Probability		0.1	0.05	0.001	0.001	0.001	0.001	0.60
$\bar{x}$	-60° to -45°	-6.83	-7.64	-0.523	-3.19	-7.01	10.9	-1.54
n		364	830	304	163	213	644	2728
s		34.5	36.2	17.7	29.0	37.2	34.5	34.3
t		-3.76	-6.08	-0.514	-1.40	-2.74	8.02	-2.34
Probability		0.001	0.001	0.70	0.20	0.01	0.001	0.05
$\bar{x}$	-45° to -30°	-12.3	-22.4	-5.75	-8.53	-3.4	1.23	-7.0
n		345.	558.	146.	356.	371.	212.	2107
s		37.1	48.4	19.5	34.1	31.5	39.5	38.7
t		-8.45	-10.9	-3.54	-4.71	-2.08	0.452	-8.3
Probability		0.001	0.001	0.001	0.001	0.05	0.70	0.001
$\bar{x}$	30° to 45°	2.32	-0.047	0.987	1.44	-8.9	-14.8	-2.5
n		255.	562.	582.	212.	123.	354.	2168
s		28.3	36.1	40.8	31.6	23.8	120.	60.3
t		1.31	-0.0308	0.583	0.662	-4.13	-7.33	-1.93
Probability		0.20	0.90	0.60	0.60	0.001	0.001	0.10
$\bar{x}$	45° to 60°	1.65	-0.775	6.46	2.40	-13.9	-1.66	-0.833
n		590.	253.	243.	216.	283.	156.	1802
s		36.4	35.4	27.5	16.0	34.9	41.7	34.0
t		1.11	-0.348	3.65	2.20	-6.69	-0.496	-1.04
Probability		0.30	0.80	0.001	0.05	0.001	0.70	0.30
$\bar{x}$	60° to 180°	1.83	0.261	0.409	-0.311	-4.40	3.45	0.041
n		1770	1782	2449	2238	2483	2014	13175
s		18.7	20.0	18.6	30.3	24.1	26.2	23.8
t		3.21	0.551	1.09	-0.485	-9.1	5.91	0.198
Probability		0.01	0.60	0.30	0.70	0.001	0.001	0.90

between observed concentration and background should be close to zero. The T statistic is

$$T = \frac{(x-\mu)\sqrt{N-1}}{s} \qquad \text{(C-1)}$$

where x is the sample mean; μ is the population mean, assumed to be zero here; N is the number of cases and s is the sample standard deviation. In the table, probabilities of 0.05 or less indicate that there is a significant chance that the sample average difference between background and observed concentrations is not equal to zero as we expect. If the average is positive, background was larger than the observed, and if negative the observed was larger than the background.

The sectors where the differences are significant are placed on a map in Figure C-1. Sectors labelled positive indicate that the background estimate using the EPA Guideline method is greater than the observed concentration. The opposite is true for the sectors labelled negative. There is no striking pattern evident on the map which would be the case if a nearby source affected the monitors. Note that Liberty Ridge (5) measured concentrations average lower than background in all directions. If we consider that site to be the most representative of background, then the EPA Guideline method overpredicts background. We recommend that further work be done on the background concentration algorithm because it can be an important part of the total model.

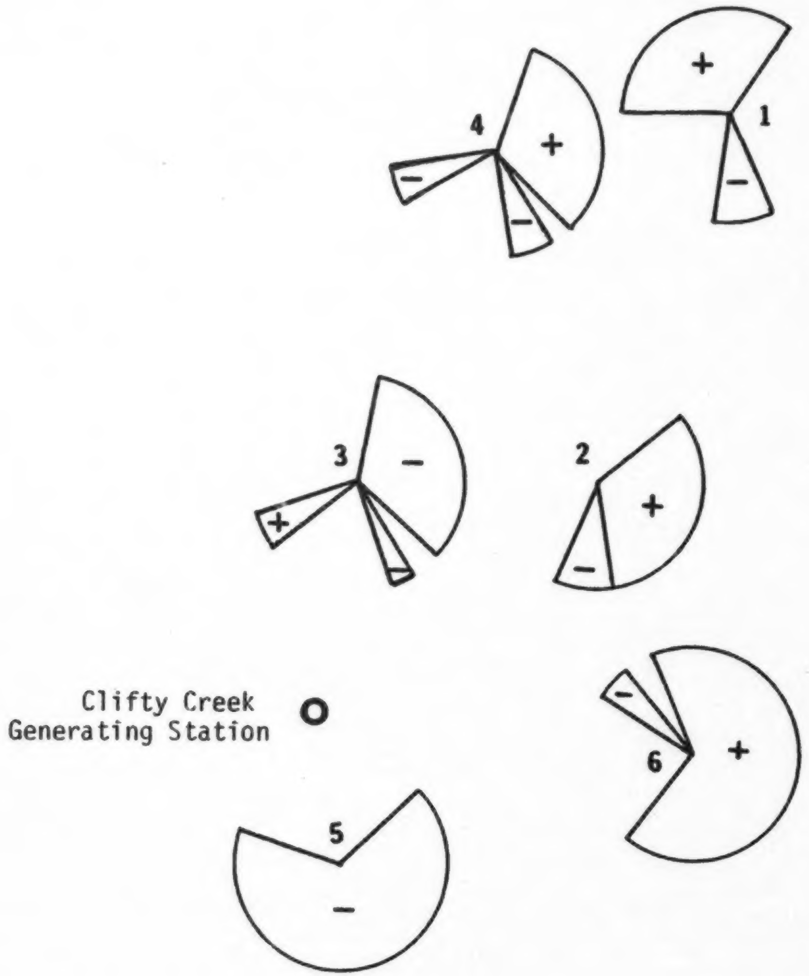

4
+
−
−
1
+
−
3
−
+
2
+
−
Clifty Creek
Generating Station
6
+
−
5
−

Figure C-1. Sectors Where the Sample Average Difference (Background Minus Observed) at the 95 Percent Significance Level is not Equal to Zero in the Clifty Creek Network During 1975. Station Numbers Refer to Table C-2.